THE UNIVERSITY OF CHICAGO

BEYOND THE NITROGEN THESIS: TEMPORAL AND SPATIAL PATTERNS OF *BRASSICA NAPUS* OILSEED DESIGN DIVERSIFICATION FOR CROP ROTATION, SOIL PEST SUPPRESSION, LIVESTOCK MANAGEMENT, AND CONVERTIBLE HUSBANDRY IN THE BRITISH AGRICULTURAL REVOLUTION(S), 1715-1830

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DEDICATION

To the forgotten men, women, and children of the past who fed hungry mouths and hungry machines by tilling, planting, and harvesting the soils. To our future farmers, who will learn from agricultural history in order to cultivate tried and true as well as new solutions.

TABLE OF CONTENTS

Acknowledgements v
Abstract vi
List of Tables ix
List of Illustrations x

CHAPTER ONE: Beyond the Nitrogen Thesis 1
- Introduction 1
- Etymology of *Brassica Napus*: The Same Species Then and Now? 12
- The British Agricultural Revolution 20
- Transforming the Commons 27
- Chapter Summaries 34

CHAPTER TWO: Rapeseed in Agricultural Improvement 43
- Introduction 43
- From Improvement to Widespread Dispersal 59
- Integrated Systems of Production 82

CHAPTER THREE: Rapeseed and Turnip Combining in Convertible Husbandry for Increased Land Use Efficiency 100
- Introduction 100
- Rapeseed for Winter Feed 111
- Rapeseed for Green Fallowing 127
- Scaling Rapeseed and Turnips to the Landscape-level in Convertible Husbandry 142

CHAPTER FOUR: Rapeseed in the Norfolk Rotation for Course Design Diversification 164
- Introduction 164
- Rapeseed in the Norfolk Rotation: Crop Diversification for a Resilient Design 180
- Pairing and Burning and the Norfolk Rotation 193
- Introduction Chronologies 202

CHAPTER FIVE: Rapeseed for Manuring to Fight Pests and Improve Soils 213
- Introduction 213
- An Early Chronology of the “Second Great Agricultural Revolution” 225
- Rapeseed Manure for Soil Disease Suppression 239
- Rape Milling, Manuring, and Planting as a Cradle-to-Cradle Design 250

CONCLUSION 268

APPENDICES
Appendix I: Methyl Bromide Use in California, 2017 278
Appendix II: Oil Crushing Mills in Britain, 1790-1865 279
Appendix III: Dispersal of Rapeseed by County 280
Appendix IV: Archives Visited for Research 283

BIBLIOGRAPHY 289

LIST OF TABLES

Table 3.1 *Brassica Napus* (Rapeseed) Substitution Pre-dates Turnips 109

Table 3.2 The Old and New Farm 148

Table 5.1 Key Dates in the Discovery of Nitrogen 217

Table 6.1 County Surveys that Document *Brassica Napus* (Rapeseed) for Improvement 278

Table 6.2 County Surveys that Document Brassica Napus (Rapeseed) for Improvement 280
General Views, Board of Agriculture

LIST OF ILLUSTRATIONS

1.1 Rape Oil Mill Tower, Devizes Castle, 2018 5

1.2 Rapeseed Field, Halsham, East Riding of Yorkshire, 2018 17

1.3 Trail Through Rapeseed Field, Halsham, East Riding of Yorkshire, 2018 42

2.1 Certificate Relating to Tithe of Rape Seed in Storthwaite, 1714 76

2.2 The Costume of Yorkshire, George Walker, 1813 78

2.3 *B. Napus* in the Eighteenth Century Production Cycle 87

2.4 Rapeseed Mill, Wakefield, United Kingdom, 1755 95

2.5 Rapeseed Mill Grinding Plans, Wakefield, United Kingdom, 1755 96

4.1 Planting Calendar from the East Riding of Yorkshire, 1828 to 1837 170

4.2 Planting Log from the East Riding of Yorkshire, 1834 to 1837 173

4.3 Planting Calendars from the East Riding of Yorkshire, 1835 to 1840 175

4.4 Planting Calendar from the East Riding of Yorkshire, 1786 to 1789 177

4.5 Planting Calendars from Durham, 1809-1914 and 1808-1815 192

4.6 Planting Calendars from the Palatine of Chester, 1794 195

5.1 Rapeseed Cake and Meal 221

6.2 Seed Crushing Mills in England, 1750-1880 279

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ABSTRACT

Historians largely agree that it was increased nitrogen fixation from new legumes as well as better nutrient cycling from larger livestock herds that allowed England to feed a growing urban population without a proportionate expansion of arable acres. This project explores the forgotten pest suppression benefits of the bright yellow alternative crop *Brassica napus* (*B. napus*), which still goes by the unfortunate common name of "rapeseed." As an alternative crop, *B. napus* may have been grown at a smaller scale but likely had a significant environmental impact by suppressing pathogens on strained soils during periods of agricultural intensification.

Today *B. napus* and its sister plants in the mustard family blanket the fields of Northern California, England, Sweden, Germany, and other hotspots of sustainable agriculture, where the seeds are crushed for oil and the meals are used as a soil amendment. Field and potting studies have shown that the crushed Brassica oilseed meals and cakes left from the press can be used as a soil amendment to support beneficial bacteria, trigger plant innate immune defenses, and release pest-fighting chemicals that help suppress soil diseases. Both the living *B. napus* roots and tilled stems also increase soil fecundity. It turns out that eighteenth-century farmers similarly used crushed *B. napus* as a manure to control pests, and they harnessed the plant for soil improvement in nearly every county in England and Scotland. As a feed, fodder, and green fallowing technique for convertible husbandry, *B. napus* was also a frost and drought hardy plant that extended the growing season into the winter and spring and protected against crop failure in polyculture with turnips. It performed well in sandy and water-logged soils that could support few plants and was sometimes the first crop planted on drained marsh or moorland to convert

acres to pasture and then arable. *B. napus* was widely dispersed by the early seventeenth century and planted at the scale of four-thousand acres on some farms.

By mining more than 200 period improvement publications and casting the nets widely at the archives to locate and review rare planting logs, tithe surveys, enclosure maps, leases, and unpublished improvement correspondence, this work presents one of the first in-depth histories of the environmental impacts of an alternative crop. This case study is among the first to explore the role of pathogen suppression improvements in the British Agricultural Revolution and highlights the need for a more careful analysis of the many other eighteenth-century soil manures and fodders that remain on the sidelines of the historiography.

Rapeseed is often excluded from the list of turnips, clover, legumes, and other rotation crops listed along with enclosure, convertible husbandry, and mechanical invention as the defining technologies of the British Agricultural Revolution. However the crop helped remake the practice of Jethro Tull's seed drill and horse-hoe by encouraging the use of mechanical technologies for fodder planting for grazing, for green fallowing, and for better crop rotation. *B. napus* cake and meal crushed at the oilseed press was drilled along with seed, and the earliest evidence of rapeseed cake manuring dates to the early seventeenth century. The technology's wider use in the eighteenth century suggests that plant manures began to play an important role at least 80 to 100 before the 1815 to 1830 dates suggested by other historians. During the eighteenth century, farmers worked to increase the oil in rapeseed cake to ensure a more potent manure. In contrast, when drilling and horse-hoeing were implemented as a Tullian method, they may have increased the risk of soil exhaustion by excluding rotation, manuring, and fallowing. Finally, historical sources show that *B. napus* plantings were used to control wireworms and molds as early as the mid-eighteenth century, and cake and meal manures were adopted to kill a range of pests by the late eighteenth to mid-nineteenth centuries. Though the multiple species names descried by the common term "turnip" are more ambiguously referenced in period sources, mid-to-late eighteenth-century authors confirm that rapeseed was the *B. napus* taxonomically identified by Linnaeus. By exploring the combining of *B. napus* with other new plants and mechanized drills and hoes, this project underscores the innovative designs that integrated technologies into temporal and spatial arrangements to increase fecundity.

CHAPTER ONE: Beyond the Nitrogen Thesis

I. Introduction

Nearly 400 years after their widespread introduction to England, the yellow flowering plants in the *Brassicaceae* family are still grown for their oil rich seeds. Today *Brassica napus* (*B. napus*) is factory farmed to make biodiesel and cooking oil, and in the early modern and eighteenth-century English landscape, the crop was similarly grown to offset trade dependency on Spanish olive oil for textile finishing, soap making, lighting, and cooking.[1] While historians have largely neglected *B. napus* and payed even less attention to its role in agricultural improvement, I uncovered numerous historical sources that confirm how the brown flakey meals left from the oil press were used by eighteenth and nineteenth century farmers as a manure to suppress wireworms and soil disease, and that planted crops were integrated as fodder and feed into the field designs that increased herd size.[2] By data mining digitized rare books and period agricultural journals this project explores the combining of *B. napus* with the defining technologies of the British Agricultural Revolution. To investigate the role of *B. napus* in the rural agricultural system, I cast nets widely during a year spent at thirty local and national

[1] Rakow G., "Species Origin and Economic Importance of Brassica " in *Biotechnololgy in Agriculture and Forestry 54: Brassica*, ed. E.C. Pua and C.J. Douglas (Springer Berlin Heidelberg, 2013), p. 7-11; D.S. Kimber and D.I. McGregor, *Brassica Oilseeds: Production and Utilization* (CAB International, 1995), p. 361-4; Jerry L. Solis et al., "Biodiesel from Rapeseed Oil (Brassica Napus) by Supported Li2o and Mgo," *International Journal of Energy and Environmental Engineering* 8, no. 1 (2017); Oliver Thring, "The Rise of Rapeseed Oil," *The Guardian*, June 12 2012; Joan Thirsk, *Alternative Agriculture: A History from the Black Death to the Present Day* (Oxford: New York : Oxford University Press, 1997), p. 6-7, 70-8.

[2] Cuthbert W. Johnson and William Shaw, "Manures and Their Prices in London," *The Farmer's Almanac and Calendar* 4 (1843), p. 93; "Farmer's Calendar-July," *The Farmer's Almanac and Calendar* 4 (1844), p. 29; Eleanor A. Ormerod, *Eleanor Ormerod, Ll D., Economic Entomologist. Autobiography and Correspondence.*, ed. Robert Wallace (New York: E.P. Dutton, 1904), p. 46-8.James Adam, *Practical Essays on Agriculture : Containing an Account of Soils, and the Manner of Correcting Them. An Account of the Culture of All Field Plants. Also, an Account of the Culture and Management of Grass-Lands; Together with Observations on Enclosures, Fences, Farms, and Farmhouses, &C. Carefully Collected and Digested from the Most Eminent Authors, with Experimental Remarks*, 7 vols., vol. 1 (United States, North America: London : Printed for T. Cadell, 1789), p. 509; H. N., "On Fallowing Land," *Agricultural magazine* 8, no. 44 (1803), p. 194. Also see Chapter 2: Rapeseed and Turnip Combining in Convertible Husbandry for Increased Land Use Efficiency and Chapter 4: Rapeseed for Manuring to Fight Pests and Improve Soils.

archives in Cambridge, London, the East Riding of Yorkshire, Edinburgh, Glasgow, Gloucestershire, Shropshire, Warwickshire, Worcester, and Wiltshire to search for *B. napus* in tithe surveys, enclosure maps, planting logs, leases, and unpublished improvement correspondence. At the Bodleian Library and many college archives at the University of Oxford, I had the opportunity to review multiple original copies of every rare book in this study in order to compare print and digitized versions. ArcGIS was used to map approximately 600 seed crushing mills clustered along the eastern coast of England and Scotland.

I argue that *B. napus* played a larger role in agricultural progress than was previously thought by functioning as a versatile design element in local cradle-to-cradle systems that reduced waste, implemented localized sourcing, and used wastes as production inputs. No single innovation worked alone to feed the industrial masses, and the multipurpose uses of *B. napus* as a drilled and horse-hoed oilseed, fodder for summer and winter grazing, dried feed stock, fallow green, and manure allows for case studies of the integration of these technologies into the whole agronomic system. In these capacities, *B. napus* was combined with new mechanical innovations for more efficient fodder cycles, with turnips or convertible husbandry, and with barley, clover, and wheat for a modified Norfolk Rotation. Crushed *B. napus* cake was used as an animal feed to support the over-wintering of animals and used as a manure for pest suppression and soil improvement. Its role in milling and enclosure points to the importance of the early introduction of privatized leases in land reform. For example, the earliest lease that I found with direct mention of rapeseed was written in 1727 and allows one of the towers at Devizes Castle in Wiltshire to be converted to a windmill for making oil.[3] The castle was nearly destroyed during the English Civil War, but the towers were repurposed by the town for

[3] "Lease for a Year of Devizes Castle, Three Houses and Two Windmills for Making Oil out of Rape Seed.," in *2278 - Miscellaneous records* (Wiltshire & Swindon Archives 1727).

industrial uses. Finally, though many alternative fodders supported larger herds and increased nitrogen cycling, *B. napus* is particularly important for having been combined with multiple other technologies. As I will argue, it was the strategic integration of these multiple uses that altered nutrient and energy recycling during the British Agricultural Revolution.

The crop illustrates the localized diversification of temporal and spatial planting designs that supported a more robust agronomic system. More than the effective implementation of any new technology, it was their combinations of that supported agricultural progress. The strategic integration of *B. napus* with multiple innovations into the whole farm system thus required the development of more complex small-scale designs. Gentleman landlords, yeoman, and tenant farmers alike revised cropping choices as well as spatial and temporal strategies according to soil type, season, and the demands of future production.

Just as modern science can help us reconceptualize the early modern landscape, the narratives of oil seed introduction, including its limitations and successes, have the potential to inform future trajectories of sustainable farming research. *B. napus* and its meal are indisputably a modern form of agricultural improvement. Today some regions of Northern California and the Pacific Northwest are blanketed with yellow fields of gold due to the powerful impacts of *B. napus* on the soil. Following decades of field trials and lab studies conducted at the US Department of Agriculture, *B. napus* and other members of the mustard family have also made a recent comeback as pest treatments and soil amendments in California's sustainable berry industries.[4] The modern technique of meal tillage integrates the brown flakes of crushed seed

[4] M. Mazzola, "Potential of Biofumigation for Soilborne Pest Control in Strawberry ". Joji Muramoto et al., "Effect of Anaerobic Soil Disinfestation and Mustard Seed Meal for Control of Charcoal Rot in California Strawberries," *International Journal of Fruit Science* 16 (2016). Mark Mazzola, Aaron Agostini, and Michael Cohen, "Incorporation of Brassica Seed Meal Soil Amendment and Wheat Cultivation for Control of Macrophomina Phaseolina in Strawberry," *European Journal of Plant Pathology* 149, no. 1 (2017).

left from the oil press into the ground with attention to the timing of water application, the depth of tillage, and the bulk poundage applied per acre. After the oil rich seeds of the *Brassicacea* family grown to make canola oil and biodiesel are crushed at the mill, the remaining meal is broadcast as a loose meal treatment or pressed into pellet form and tilled into the earth.[5]

A growing body of soil microbial studies and field trials have clarified the mechanisms by which Brassica seed meal tillage is less toxic to humans and the environment yet delivers comparable results to broad spectrum biocides—a class of chemicals destructive to many classes of soil pathogens due to combined pesticidal, herbicidal, and fungicidal functionality. Upon contact with water, the highly concentrated glucosinolates in Brassica seed meal break down to isothiocyanate—a volatile chemical fumigant that directly targets a variety of pests.[6]

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[5] M. F. Cohen, H. Yamasaki, and M. Mazzola, "Brassica Napus Seed Meal Soil Amendment Modifies Microbial Community Structure, Nitric Oxide Production and Incidence of Rhizoctonia Root Rot," *Soil Biology and Biochemistry* 37 (2005); Mark Mazzola, Shashika S. Hewavitharana, and Sarah L. Strauss, "Brassica Seed Meal Soil Amendments Transform the Rhizosphere Microbiome and Improve Apple Production through Resistance to Pathogen Reinfestation," *Ecology and Epidemiology* 105 (2015). M. F. Cohen and M. Mazzola, "A Reason to Be Optimistic About Biodiesel: Seed Meal as a Valuable Soil Amendment," *Trends in Biotechnology* 22 (2004).

[6] Nikoletta Ntalli and Pierluigi Caboni, "A Review of Isothiocyanates Biofumigation Activity on Plant Parasitic Nematodes," *Phytochemistry Reviews* 16, no. 5 (2017). M. Mazzola et al., "Mechanism of Action and Efficacy of Seed Meal-Induced Pathogen Suppression Differ in a Brassicaceae Species and Time-Dependent Manner," *Phytopathology* 97 (2007). D. M. N. Weerakoon et al., "Long-Term Suppression of Pythium Abappressorium Induced by Brassica Juncea Seed Meal Amendment Is Biologically Mediated," *Soil Biology and Biochemistry* 51 (2012). L. R. Elberson et al., "Toxicity of Rapeseed Meal-Amended Soil to Wireworms, Limonius Californicus (Coleoptera: Elateridae)," *Journal of Agricultural and Urban Entomology* 13, no. 4 (1996). Cohen, Yamasaki, and Mazzola, "Brassica Napus Seed Meal Soil Amendment Modifies Microbial Community Structure, Nitric Oxide Production and Incidence of Rhizoctonia Root Rot." M. Mazzola et al., "Suppression of Specific Apple Root Pathogens by Brassica Napus Seed Meal Amendment Regardless of Glucosinolate Content," (2001). M. Mark, M. F. Cohen, and U. A. Tree, "Suppression of Rhizoctonia Root Rot by Streptomyces in Brassica Seed Meal-Amended Soil" *Phytopathology* 95 (2005). Mazzola, Agostini, and Cohen, "Incorporation of Brassica Seed Meal Soil Amendment and Wheat Cultivation for Control of Macrophomina Phaseolina in Strawberry," *European Journal of Plant Pathology* 149 (2017). M. Mazzola and K. Mullinix, "Comparative Field Efficacy of Management Strategies Containing Brassica Napus Seed Meal or Green Manure for the Control of Apple Replant Disease," *Plant Disease* 89 (2005).

1.1 *Rape Oil Mill Tower, Devizes Castle, 2018,* Amy Coombs. In 1643 Devizes Castle was occupied by Royalist troupes and subsequently besieged by Parliamentarian forces during a series of battles that ended in 1645, when Oliver Cromwell invaded the town and castle. The stonework was largely dismantled, however the two towers remained and were later rented by local merchants. The tower (top image), which is located on the far left of the castle (bottom image), was turned into a windmill and used for rape oil milling in 1727. The second tower on the right of the castle (bottom image) may have also been used as a rapeseed mill. The castle was purchased by a tradesman named Valentine Leach in 1838, and the present Victorian reconstruction was built for beauty rather than fortification by the Leach family during a series of projects that began in 1842 and continued through the 1860s.

Though Devizes Castle is private and does not allow public tours, I was invited to visit the grounds during my trip to the archives. I surprised the building manager with my archival findings showing rape oil milling in Devizes in the early eighteenth century. Based on the local tobacco mills at work in the nineteenth century when the castle was rebuilt, the managers assumed that snuff was the primary local historical trade. However textiles and cereals were also major markets in the seventeenth and eighteenth centuries.

Second, the nutrients and chemicals in the meal may serve as a substrate for beneficial microbes that compete with diseases and sometimes directly fight them, and third, some Brassica seed meals trigger plant innate immune defenses and combine forces with resident bacteria.[7]

Researchers have shown comparatively high yields when comparing apple orchards and strawberry fields treated with *B. napus* and those treated with chemicals like Chloropicrin or Methyl Bromide.[8] For example, in a 2015 USDA study plots were planted with apple trees and infected with apple replant disease before receiving treatment with 1,3-dichloropropene/chloropicrin or seed meal. Two Brassica seed meal treatments were tested—mixtures of Chinese and white mustard (*Brassica juncea* combined with *Brassica Sinapis alba*) and mixtures of Chinese mustard and rapeseed meal (*B. juncea* combined with *B. napus*). After four growing seasons, seed meal amended soils were more resistant to reinfestation and showed enhanced tree performance, however some seed meal formulations were mildly phytotoxic depending on the season of application.[9] In potting studies *B. napus* and other seed meals have also suppressed pathogenic fungi like *Rhizoctonia spp*. and introduced isolate of *Rhizoctonia solani AG-5*. Overall disease suppression was associated with increases in resident beneficial

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[7] Mark, Cohen, and Tree, "Suppression of Rhizoctonia Root Rot by Streptomyces in Brassica Seed Meal-Amended Soil " *Phytopathology* 95 (2005). M. F. Cohen and M. Mazzola, "Resident Bacteria, Nitric Oxide Emission and Particle Size Modulate the Effect of Brassica Napus Seed Meal on Disease Incited by Rhizoctonia Solani and Pythium Spp," *Plant and Soil* 27 (2006). Clarissa Potgieter, Misha De Beer, and Sarina Claassens, "The Effect of Canola (Brassica Napus) as a Biofumigant on Soil Microbial Communities and Plant Vitality: A Pot Study," *South African Journal of Plant and Soil* 4 (2013). Mazzola, Hewavitharana, and Strauss, "Brassica Seed Meal Soil Amendments Transform the Rhizosphere Microbiome and Improve Apple Production through Resistance to Pathogen Reinfestation" *Ecology and Epidemiology* 105 Cohen, Yamasaki, and Mazzola, "Brassica Napus Seed Meal Soil Amendment Modifies Microbial Community Structure, Nitric Oxide Production and Incidence of Rhizoctonia Root Rot," *Soil Biology and Biochemistry* 37 (2005).

[8] Mazzola et al., "Suppression of Specific Apple Root Pathogens by Brassica Napus Seed Meal Amendment Regardless of Glucosinolate Content," *Phytopathology* 81 (2001). Mazzola, Hewavitharana, and Strauss, "Brassica Seed Meal Soil Amendments Transform the Rhizosphere Microbiome and Improve Apple Production through Resistance to Pathogen Reinfestation," *Ecology and Epidemiology* 105 (2015). Mazzola, "Potential of Biofumigation for Soilborne Pest Control in Strawberry ".

[9] Mazzola, M., Hewavitharana, S. S., and Strauss, S. L., 'Brassica seed meal soil amendments transform the rhizosphere microbiome and improve apple production through resistance to pathogen reinfestation,' *Phytopathology*, 2015, 105: 460-469.

microbes like *Streptomyces spp*.[10] Seed meal treatments often offer effects shortly after application and persist through the growing season, although the soil continues to benefit from increased nutrient loads and beneficial microbial ecology years after application. Benefits are both immediate and long-lasting; acute and gradual. In contrast, plots treated with Methyl Bromide, Chloropicrin, or Telone divert back to the disease state after several growing seasons, and sometimes require increasing loads of chemical.[11]

Very few sustainable treatments have convinced conventional growers to reduce or abandon chemical applications, but according to a United States Department of Agriculture report:

> While such an approach would appear an implausible means to control the plethora of soil borne pathogens affecting strawberry, the strategy when utilized independently (seed meal formulations) or as part of an integrated system has demonstrated effectiveness for the control of biologically complex diseases.[12]

Per acre, strawberries cost $30,000 to plant, and revenue tops $50,000, which is at least three times more than lettuce, artichokes, and grain. Each year the United States strawberry industry produces about 1.6 billion pounds of strawberries valued at $3.5 billion.[13] Based on data from 2017, even California's environmentally progressive agricultural industry continues to apply about 8,517 pounds of Methyl Bromide product each year through Federal exemptions to the Montreal Protocol secured decades after near total phase outs in Western Europe.[14] One of the

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[10] Mazzola, M., Brown, J., Izzo, A. D., and Cohen, M. F. 2007. Mechanism of action and efficacy of seed meal-induced pathogen suppression differ in a Brassicaceae species and time-dependent manner. *Phytopathology,* 97:454-460.

[11] Mazzola, M., Hewavitharana, S. S., and Strauss, S. L., 'Brassica seed meal soil amendments transform the rhizosphere microbiome and improve apple production through resistance to pathogen reinfestation,' *Phytopathology*, 2015, 105: 460-469.

[12] Mazzola, "Potential of Biofumigation for Soilborne Pest Control in Strawberry ".

[13] Agricultural Marketing Resource Center, "Strawberries " https://www.agmrc.org/commodities-products/fruits/strawberries.

[14] This represents original data analysis using Microsoft Excel in the form of total pounds and acreage using the California Pesticide Information Portal. I ran a query by crop (Strawberry) and chemical (Methyl Bromide) of the most recent data collected in 2017 for all 58 counties in California. See Appendix 1 for data. California Department of Pesticide Regulation, "Pesticide Use Report Query " https://calpip.cdpr.ca.gov/county.cfm?ds=PUR. Note that

benefits of *B. napus* is that it is more targeted and less comprehensive than Chloropicrin and Methyl Bromide, which sterilize the soil and kill both beneficial and plant-killing organisms. Biocide treatments create a vacuum for opportunistic pathogenic colonizers. In contrast, *B. napus* may contribute pathogen suppression while stimulating beneficial microbes, and it is not so comprehensive as to eradicate entire community structures in the soil.

B. napus has also been shown to release glucosinolate compounds from the cut stems used as green manure or tilled into the earth as compost.[15] Plantings may also contribute mild soil pathogen suppression benefits as the roots of Brassica species release low levels of glucosinolates into the soils. The pest suppression benefits from the roots and cut stems are minimal when compared to the more potent contributions of seed meals. However, plantings and green manures may be less likely to introduce unintended soil allelopathy. *B. napus* has been noted in the historical literature as particularly exhausting to soils, though modern reports consider plantings to be protective against soil erosion and nitrate leaching because it is grown as a winter cover crop.[16]

Though eighteenth century farmers did not think in modern scientific terms and primarily used *B. napus* manures to grow turnips and cereals, they collected a surprising amount of

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most states do not track pesticide applications through a transparent system and that Federal reporting has been reduced over past years. California is one of the only states that makes such data readily available.

[15] Green manure usually consists of uprooted or mowed cover crops left as mulch for soil amendment. Sometimes plants are tilled into the earth as a compost treatment. Mazzola and Mullinix, "Comparative Field Efficacy of Management Strategies Containing Brassica Napus Seed Meal or Green Manure for the Control of Apple Replant Disease." Mazzola, "Potential of Biofumigation for Soilborne Pest Control in Strawberry," *Plant Disease* 89 (2005). Ntalli and Caboni, "A Review of Isothiocyanates Biofumigation Activity on Plant Parasitic Nematodes," *Phytochemistry Reviews* 16 (2017).

[16] R. Davis and L. Davis, *De Re Rustica; or, the Repository for Select Papers on Agriculture, Arts, and Manufactures* (London: R. Davis, and L. Davis, 1769), p. 3-4. John Middleton, *General View of the Agriculture of Middlesex : With Observations on the Means of Its Improvement, and Several Essays on Agriculture in General. Drawn up for the Consideration of the Board of Agriculture and Internal Improvement*, ed. Agriculture Board of and John land surveyor Middleton, 2nd ed. ed. (London : sold by G. and W. Nicol: Printed for Sherwood, Neely, and Jones, 1813), p. 372. Also see the section on soil exchustion from B. napus in Chapter 1: Rapeseed for Agricultural Improvement; M. C. Robson et al., "The Agronomic and Economic Potential of Break Crops for Ley/Arable Rotations in Temperate Organic Agriculture," *Advances in Agronomy* 77 (2002).

information about the crop. In 1770 Arthur Young wrote that "Rape-dust from the oil mills is a capable article with them, having found it of prodigious benefit to all sorts of land; but it is chiefly laid on their barley lands…"[17] Similarly, "In the district of Holkham, rape-cake is very generally, perhaps I might say universally, used," reads a hand scribbled slip of paper held at the British Library in an unpublished collection of Young's letters. "They spread a ton on three or four acres, usually sowing it (about eleven or twelve bushels to the acre) for wheat or turnips, or for both. It is a highly effective manure,"[18] according to the manuscript. In 1790 Christopher Baldwin wrote that "rape oil cake was known to be an excellent manure." He attributed its soil benefits to the "quantity of oil contained in it, though that quantity must be very small indeed…".[19] And in the 1804 *General View of the Agriculture of the County of Norfolk* we learn that Mr. England of Binham used "much rape cake, and this year his turnips thus manured are his best…."[20]

Sources also show that rapeseed was grown as a fodder, green fallow plant, and rotation crop to support larger herd sizes and soil improvement. In a mid-eighteenth century letter written by Sir. Digby Legard to the Society of Arts, England was said capable of having much superior soils to Switzerland "if our farmers are so much more skillful than theirs that we can in the common management, I mean by the culture of turnips, clover, rape, &c, have a beneficial crop every year."[21] Sometimes the horse-hoe was used. In the 1753 Plan of Mr. Randall's Farm in

[17] Arthur Young, *A Six Months Tour through the North of England*, 4 vols. (W. Strahan, 1770), p. 182.
[18] Arthur Young, "The Elements and Practice of Agriculture, Unpublished," in *Add MS 34821-34854*, ed. British Library (Western Manuscripts, 1818).
[19] Christopher Baldwin, "On Oil Used as Manure," in *Annals of Agriculture and Other Useful Arts*, ed. Arthur Young (London: Young, Arthur 1790), p. 501.
[20] Arthur Young, *General View of the Agriculture of the County of Norfolk* (G. and W. Nicol, 1804), p. 420.
[21] F. Forbes and J. Tull, *The Extensive Practice of the New Husbandry, Exemplified on Different Sorts of Land, for a Course of Years; in Which the Various Methods of Ploughing, Hoeing ... And Every Other Process in Agriculture, Recommended by Mr. Tull, ... Etc., Are Considered ... To Which Is Added an Appendix Containing ... Directions for Practising Husbandry, ... The Second Edition* (W. Tayler, 1786), p. 167.

Yorkshire, “The grasses and rapes are handplanted at proper distances. Then horse hoed, by which a good fallow is made for wheat and Barley."[22] Randall’s farm rotated 200 acres each of rape, grass, barley, wheat, and turnips plus 400 acres of sainfoin. A one-page entry on rape in an agricultural journal handwritten around this same time shows that the crops were sown in fallows and for green winterfeed. According to the entry on rape, while the crop may have drawn from the ground, this was repaid in dung from the sheep that fed on the plantings.[23] In 1793 Arthur Young published advice that with turnips, rape, and tares as fodder to support grazing and thus manure contributions a “smaller number of acres frequently produce more corn than a greater from the improvement on the land by the sheep fold.”[24] Writing about Leicester in 1809, William Pitt described how coleseed—a name that was often used as a synonym for rapeseed—was an ideal fodder. He wrote: “the eating off the cole with sheep or cattle… would so dung the land so firm a root as to cause it to grow very luxuriantly.”[25] It the 1811 *General View of the Agriculture of the County of Cambridge*, William Gooch described that coleseed was planted for sheep grazing. “The sheep are commonly put to the coleseed about the 11th of October, and have liberty to go into the whole field as soon as they are turned in,” wrote Gooch. He described how the sheep commonly ate the outleaves of the coleseed, allowing the heart and stalks to last.

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[22] "Plan of Mr. Randall’s Farm in Yorkshire, as Contained in a Letter to Thomas Hope of Rankeilor Esq.," in *Papers of the Family of Fletcher of Saltoun (previously of Innerpeffer), with Some of Abernethy, Lords Saltoun.*, ed. National Library of Scotland (National Library of Scotland Manuscript Archives 1753).

[23] Lord Milton, "Otp Emud, Handwriiten Book on Agriculture " in *Notes on agriculture by Lord Milton. Notes on Agriculture and Horticulture by Lord Milton, with Other Miscellaneous Notes.*, ed. National Library of Scottland (National Library of Scotland Manuscript Archives Mid Eighteenth Century), p. 109.

[24] Arthur Young, *Annals of Agriculture, and Other Useful Arts*, 46 vols., vol. 21 (London: Arthur Young, 1793), p. 78-9.

[25] William Pitt, *General View of the Agriculture of the County of Leicester; with Observations on the Means of Its Improvement, Published by Order of the Board of Agriculture and Internal Improvement. By William Pitt of Wolverhampton. To Which Is Annexed a Survey of the County of Rutland by Richard Parkinson*, ed. Board of Agriculture (Richard Phillips, Bridge street, 1809), p. 81.

"After the sheep have eaten the cole-seed, the stalks are often permitted to stand for seed, and will frequently produce twenty-six to forty bushels per acre," added Gooch.[26]

As the other chapters of this dissertation will show, even in the early seventeenth century *B. napus* was known as a beneficial crop as it could prepare poor, sandy soils for cash crops of cereals. The cake from the oilseed press was used in manure recipes as early 1634, and by the early eighteenth century, *B. napus* manures became more frequently recommended in improvement publications. Farmers even worked to modify the oil concentration in the cake so as to perfect manures for soil treatments. By the end of the century, agricultural improvers began to describe the use of *B. napus* cake manure to kill wireworms, though this use became more frequently cited in the nineteenth century. However field plantings of *B. napus* were noted for their ability to suppress soil diseases through the eighteenth century.

Based on these findings, even if *B. napus* was planted on fewer plots and on less acreage than clover, turnips, and the traditional fodders, it may have had a significant environmental benefit by serving as a tool for farmers who worked to improve poor soils and rid fields of pests. In areas undergoing agricultural intensification, it was especially important to bring poor and pest-ridden soils into cultivation. The potential to treat problems at the small-scale was important, even if *B. napus* was not planted as widely as other fodders. Though it is difficult to determine national trends from the multitude of disaggregated local examples in this study, future chapters will show that *B. napus* was used to maximize gains in most counties in England and Scotland. Additional research will be needed to estimate the frequency of adoption in terms of the number and size of fields planted in rapeseed in economically important regions during the long eighteenth century. However this project confirms the specialized uses of *B. napus* to

[26] William Gooch, *General View of the Agriculture of the County of Cambridge* (Sherwood, Neely, and Jones, 1811), p. 114-15.

stabilize productivity in areas prone to crop failure, to extend plantings into the cold season, and to treat soil pests. This suggests a very different niche for alternative fodders, which may have been more strategically integrated through trial and error to solve specific environmental problems at the local and regional scale. Thus the economic impact of *B. napus* cannot be underestimated regardless of whether it was planted on a smaller abundance of farms and in fewer acres than the other new crops that commonly define the British Agricultural Revolution.

II. Etymology of *Brassica Napus*: The Same Species Then and Now?

To understand the potential impacts of *B. napus* on historical soils, we must first examine whether the plant referenced in eighteenth-century texts is the same species grown today. The Brassicaceae plant family is sometimes called the cabbage or mustard family, and consists of both oil producing and non-producing species. Broccoli, cauliflower, and kale are Brassica species, for example, while the Brassica oilseeds and field fodders are more narrowly characterized by their tall yellow flowers. Much of this project focuses on the Brassica flower called "rapeseed" or "rape" by both historical and modern farmers.[27] Though rapeseed is most often said to be *Brassica napus*, some ambiguity remains over the taxonomic classification. A Canadian Directive on *The Biology of Brassica napus L. (Canola/Rapeseed)* indicates that the term rapeseed refers to oilseeds from the species *B. napus* and *B. rapa*, while the term "canola" refers to varieties of oilseed bread to be more edible and palatable for human consumption.

[27] Canadian Food Inspection Agency, "The Biology of Brassica Napus L. (Canola/Rapeseed)," https://www.inspection.gc.ca/plant-varieties/plants-with-novel-traits/applicants/directive-94-08/biology-documents/brassica-napus-l-/eng/1330729090093/1330729278970#b25.

Rapeseed was the most commonly planted Brassica in the early modern landscape and one of the most commonly studied Brassicas at the USDA, however many other Brassica oilseeds were economically important to the early modern landscape just as they are today.

The early modern "rape" in "rapeseed" may be derived from the historical names for the blades used for threshing. According to the Oxford English Dictionary, the term "rape" was used from 1404 to 1888 to describe files and other devices that might be found in a tool shed along with an axe or hammer. According to a passage from 1473, "The toel belongeth to my crafte as saws, hammers, and rapis files," and in 1533 it was written "I have seen some that have cut it first with a saw, and than raped the pieces with a rape.[28]" These examples show that the term 'rapis' represented objects from the tool shed, while 'raped' signifies action performed with the tool object, but they do not tell us how our definitions of a metal or wooden tool expanded to describe an agricultural cultivar. However *B. napus* was one of many crops threshed with blades or files.

"Rapeseed" is often used interchangeably with the term "coleseed" in the primary and secondary literature. Historian Joan Thirsk conflates rapeseed and coleseed in the index of *The Rural Economy of England*. She writes *"see* Rapeseed" next to the alphabetical listing for coleseed.[29] The historical sources are similarly likely to list "rapeseed or coleseed" as if they could be one in the same even while distinguishing other Brassica oil seeds like turnip, white mustard, yellow mustard, and cabbage. In the *Communications to the Board of Agriculture* in 1805, Joseph Scott wrote that coleseed is said to have been called rapeseed in the London

[28] Oxford English Dictionary, *rape, n.6* http://www.oed.com.proxy.uchicago.edu/view/Entry/158146, accessed 02/09/2017.
[29] Joan Thirsk, *The Rural Economy of England : Collected Essays*, ed. Joan Thirsk, History Series (Hambledon Press) ; (London: Hambledon Press, 1984), p. 107.

Market.[30] In a section on cole in *The Complete Farmer*, the names of the two plants are used interchangeably and we learn “This kind of plant is sometimes cultivated under the name of rape.”[31] Though some may have use “coleseed” as a generic description of the many Brassica oilseeds used for similar purposes, and others may have distinguished between “rape” and “cole,” such complexities can often be inferred from the structure of sentences and contextual indicators in the larger work.

In the mid twentieth century, historian George Fussell similarly wrote that modern *Brassica napus* was identical with early modern rapeseed. He published an article in the academic journal *Nature* that linked the modern taxonomic names of *B. napus* and other Brassicas to the early modern English common names based on the geography and chronology of introduction, species knowledge of European source stock, and the import and export histories in England and Europe.[32] Fussell suggested that the plant we now call rapeseed or *Brassica napus* was the same as the plant called rape or rapeseed by the eighteenth century farmer. Modern farmers and scientists do indeed use the common name “rapeseed” even in academic publications.[33] Historical sources are not without ambiguity but consistently describe rapeseed and coleseed as *Brassica napus*.

Brassica napus was first classified by the Swedish botanist Carl Linnaeus. An entry in the second volume of his 1753 *Species Plantarum* describes the plant’s sandy, maritime

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[30] Joseph Scott, "Fens Xli," in *Communications to the Board of Agriculture, on Subjects Relative to the Husbandry and Internal Improvement of the Country*, ed. Great Britain. Board of Agriculture (W. Bulmer, 1805).
[31] R. Baldwin, *The Complete Farmer; or, General Dictionary of Agriculture and Husbandry: Comprehending the Most Improved Methods of Cultivation; the Different Modes of Raising Timber, Fruit, and Other Trees; and the Modern Management of Live-Stock: With Descriptions of the Most Improved Implements, Machinery, and Farm-Buildings.*, 5th ed. ed., 2 vols., vol. 1 (London: (London): Printed for R. Baldwin, Rider and Weed), 1807), p. 3D2-3E.
[32] G. E. Fussell, "History of Cole (Brassica Sp.)," *Nature* 176, no. 4471 (1955): p. 48-51.
[33] Solis et al., "Biodiesel from Rapeseed Oil (Brassica Napus) by Supported Li2o and Mgo." Elberson et al., "Toxicity of Rapeseed Meal-Amended Soil to Wireworms, Limonius Californicus (Coleoptera: Elateridae)." Thring, "The Rise of Rapeseed Oil."

habitats.[34] By the beginning of the nineteenth century, agricultural improvers like William Fordyce Mayor related the species name and common name in print. In his 1813 General View of the Agriculture of Berkshire, Fordyce Mayor began a section on Rape or Coleseed as follows:

> It is the *Brassica napus* of Linnaeus, and though the preparation for it is in almost every respect similar to that for turnips, it will thrive on soils where the latter will not… Rape is usually sown broad cast at the rate of two pounds of seed per acre. If drilled, less is sufficient…[35]

John Wilson similarly dedicated a section to rape in his 1849 *The Rural Cyclopedia: Or a General Dictionary of Agriculture*. He wrote that "the common rape, or winter rape, or coleseed *Brassica napus*" also grew wild in ditches and banks.[36]

This project spans the generations when botanists and agricultural writers debated the ambiguities of taxonomic categories. It is perhaps no surprise that earlier texts reflect ambiguities over taxonomy and plant identification. For example, in 1753 the improver Edward Lisle wrote:

> Charlock, rape, and turnip-seed are not easily distinguishable, and sheep will eat of the rape-roots as well as of the turnip roots, and it is of the same nature, and the same sort of land agrees with it; only the rape-root does not grow so large as the true turnip-root does; yet many famers about Burbage buy of it to sow.[37]

This suggests that farmers may have at times planted turnip seed, mustard seed, or other Brassica species as part of a rapeseed improvement project. In 1756 Thomas Hale similarly noted ambiguity over the classification of coleseed, which he also called rapeseed in the text. Hale wrote:

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[34] Carl Von Linné, *Species Plantarum : Exhibentes Plantas Rite Cognitas Ad Genera Relatas, Cum Diferentiis Specificis, Nominibus Trivialibus, Synonymis Selectis, Locis Natalibus, Secundum Systema Sexuale Digestas*, 2 vols., vol. 2 (Berlin : Junk, 1753), p. 666.
[35] William Fordyce Mavor, *General View of the Agriculture of Berkshire: Drawn up for the Consideration of the Board of Agriculture and Internal Improvement.* (Richard Phillips, Bridge Street, Blackfriars, 1809), p. 219.
[36] John M. Wilson, *The Rural Cyclopedia, or a General Dictionary of Agriculture : And of the Arts, Sciences, Instruments, and Practice, Necessary to the Farmer, Stockfarmer, Gardener, Forester, Landsteward, Farrier, &C*, ed. John M. Wilson, 4 vols., vol. 4 (Edinburgh; London: A. Fullarton, 1849), p. 17.
[37] Edward Lisle, *Observations in Husbandry* (London: Hughs, J., 1757), p. 238.

> There are three kinds of plants, each containing several species, and distinguished by different Names, but very nearly agreeing in their flowers, seed vessels, and other general circumstances, these are, 1.The Cabbage Kind, 2.The Turnip Kind; and 3.The Navew Kind. The confusion that has been made among these, has been one occasion of the uncertainty about the Coleseed Plant.[38]

Hale clarifies this confusion by describing methods for distinguishing plants based on the stalk and length of root.

During the decades when the Linnaean system was becoming more widely accepted, the species names for rapeseed were sometimes ambiguous. Though it is complicated to use translated text when raising questions of etymology, Duhamel du Monceau published 1759 correspondence in French that indicated "napus sylvestris, or wild navew, generally known by name of rape or cole seed, is much cultivated in the isle of Ely, and some other parts of England, for its seed, from which the rape oil is drawn."[39] In the 1776 *Agricultura*, a Mr. Miller "refers to Navew, Rape, or Cole, to the title of Napus, all being of the same species."[40]

Richard Weston wrote that *Brassica Napus Sylvestris* was "Wild Navew, or Rape-seed." In contrast, *Brassica Napus Sylvestris Alba* was "White Navew, or French Turnip."[41]

Such debates suggest period confusion between the yellow flowering field turnips and mustards which look similar to *B. napus* and were also planted for fodder. Today *wild navew is*

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[38] Thomas Hale, *A Compleat Body of Husbandry. Containing, Rules for Performing ... The Whole Business of the Farmer and Country Gentleman ... Compiled by John Hill from the Original Papers of the Late Thomas Hale, Etc.*, vol. 3 (Dublin: Wilson, P. & Exshaw, J., 1757), p. 502-04.

[39] Duhamel du Monceau, *A Practical Treatise on Husbandry, Etc.*, 4 vols., vol. 1 (London: J. Whiston, B. White, R. Baldwin, W. Johnston, P. Davey, B. Law, 1759), p. 322-23

[40] Matthew Peters, *Agricultura, or, the Good Husbandman Being a Tract of Antient and Modern Experimental Observations on the Green Vegetable System : Interspersed with Exemplary Remarks on the Police of Other Nations : To Promote Industry, Self-Love, and Public Good, by Reducing Forests, Chaces, and Heaths into Farms : Together with Some Observations on the Large Exports That Must Unavoidably Arise from Thence, as Well as the Increase of Population* (London: W. Flexney, 1776), p. 74.

[41] R. Weston, *The English Flora, or, a Catalogue of Trees, Shrubs, Plants, and Fruits, Natives as Well as Exotics, Cultivated for Use or Ornament in the English Nurseries, Greenhouses, and Stoves: Arranged According to the Linnaean System : With the Latin Trivial and Common English Names and an English Index Referring to the Latin Names : Also a General Catalogue of Seeds for the Kitchen-Garden, Flower-Garden, Grass-Lands, &C. Usually Raised for Sale, and Those Annually Imported from America* (1775), p. 62.

1.2 *Rapeseed Field, Halsham, East Riding of Yorkshire, 2018,* Amy Coombs. In 2018 rapeseed blanketed large fields in the village Halsham in the East Riding of Yorkshire, where I lived to study at the archives in Kingston upon Hull in Beverley. This field was located across the street from the Tudor All Saints Church and Halsham House where I stayed in former servants quarters. At the Beverley Treasure House I found a 1793 valuation of William Brown's property that listed a rape close in Halsham. [42] An 1817 survey of Brown's property also lists the rape close in Halsham.[43]

[42] "Survey, Valuation and Rental of Edward Constable," in *Chichester-Constable Family and Estate Records*, ed. East Riding of Yorkshire Council (Beverley Treasure House, 1793).
[43] "Survey," in *Chichester-Constable Family and Estate Records*, ed. East Riding of Yorkshire Council (Beverley Treasure House, 1817).

classified as B. napus var. napus, or rapeseed, though the taxonomic distinction between wild and white navey is unclear.[44] There is no proper taxonomic category named *B. napus sylvestris,* and the wild turnip *B. rapa subsp. sylvestris* identified by Carl Linnaeus is designated as unverified and undescribed in modern taxonomic indexes.[45] *Subspecies of B. rapa are sometimes generally called "field mustards" or "field turnips," and though these plants also offer the benefit of soil pathogen suppression and serve as a hardy forage, though some cultivars are suspected of poisoning livestock.*[46]

Modern farmers know the white turnip bulb that serves as cattle feed as B. rapa subsp. rapa. However as the bulbous white turnip roots have a yellow flower that looks similar to field turnips or field mustard, it is possible that some farmers might have confused the species in the eighteenth century.[47] Though an etymology can be reconstructed for turnips with the help of eighteenth-century literature, this is a massive project that exceeds the focus of the current dissertation. Turnips are more ambiguously referenced in the sources consulted. As plants grown for turnip bulbs can also be used as a green fodder species despite the risk that grazing can impact the success of the root crop, it is difficult to say with certainty which species of turnip is referenced in a historical source. Rapeseed is more reliably categorized as *B. napus,* however

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[44] "Henriette's Herbal Homepage," https://www.henriettes-herb.com/plants/brassica/napus-var-napus.html.

[45] In the GRIN database comments for Brassica rapa L. subsp. sylvestris read "lack of valid publication verified from original literature" and conflicting Lamarckian and Linnaean taxonomies are noted under "Purchas & Ley," it is likely that this category represents period confusion between rapeseed and other Brassica oilseed species. See United States Department of Agriculture, "U.S. National Plant Germplasm System, Germplasm Resources Information Network (Grin-Taxonomy)," in *Brassica rapa L. subsp. sylvestris* (Beltsville, Maryland Agricultural Research Service, National Plant Germplasm System, 2020). Linné, *Species Plantarum : Exhibentes Plantas Rite Cognitas Ad Genera Relatas, Cum Diferentiis Specificis, Nominibus Trivialibus, Synonymis Selectis, Locis Natalibus, Secundum Systema Sexuale Digestas*, 2, p. 662; "Brassica Rapa Subsp. Sylvestris," http://www.maltawildplants.com/CRUC/Brassica_rapa_subsp_sylvestris.php.

[46] "Brassica Rapa Subsp. Sylvestris". "Field Mustard ", https://plants.usda.gov/plantguide/pdf/pg_brrar.pdf. "Brassica Rapa L.," https://www.hort.purdue.edu/newcrop/duke_energy/Brassica_rapa.html.

[47] The Editors of Encyclopaedia Britannica, "Turnip," Encyclopædia Britannica, inc., https://www.britannica.com/plant/turnip.

this reflects a methodological focus on the economic importance of the crop for oilseed and its other environmental uses.

In addition to the debates over popular period species taxonomy, it is also possible that historical cultivars of the same species varied in oil and chemical content. Today these variables vary greatly between *B. napus* rapeseed varieties. In 1943 the "Argentine" cultivar of *B. napus* rapeseed was bred to have only 40.5 percent oil and high levels of glucosinolates, while the 1982 "Westar" cultivar had 44.3 percent oil but lower glucosinolate concentrations.[48] At least eleven cultivars were bread during this time to maximize oil and glucosinolate concentration but reduce erucic acid—a mildly toxic compound that makes rapeseed oils unpalatable. The "Midas" *B. napus* cultivar released in 1973 consisted of 43.8 percent seed oil and had both high glucosinolate and low erucic acid concentrations.[49] In 1986 the "European Winter Rape" cultivar of *Brassica napus* likely preferred during the long eighteenth century was bread to have a higher concentration of glucosinolates but low erucic acid.[50]

Thus, the rapeseed grown in eighteenth-century England was not a chemical replicate of the modern crop, though its species designation as *B. napus* combined with the similarities in economic and environmental uses shows that the relationships between culture and plant spanned period boundaries. The modern seeds are likely much higher in glucosinolate content, more palatable, and less likely to be mildly toxic to humans and animals. Though the eighteenth century literature may not directly map to modern taxonomies, this project is possible because the terms "rape," "rapeseed," and "cole" or "coleseed" are consistently described as *Brassica napus* in the historical literature. At least by the end of the eighteenth century, farmers

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48 Downey R. K. and Rakow G. F. W., "Rapeseed and Mustard," in *Principles of Cultivar Development: Crop Species*, ed. W.R. Fehr, E.L. Fehr, and H.J. Jessen (Macmillan, 1987), p. 443.
49 Ibid.
50 Ibid., p. 456.

consistently defined “rapeseed” and “coleseed” as *B. napus*. However even if eighteenth century field mustards or turnip seeds were sometimes mistaken for rapeseed, the observations of environmental impacts were still salient. Many of the golden flowered *Brassica* species have high glucosinolate concentrations and offer potential environmental benefits. In fact, today mixtures of Brassica species are sometimes thought more effective at suppressing soil pathogens than treatments that rely on rapeseed alone. This project thus relies on the words of historical actors, who most commonly use “rape” or “rapeseed,” though some preferred “cole” or “coleseed.” Both the eighteenth century and modern rape share a common economic and environmental use; crushed cake from the oil mill was and is used as a manure to improve soils. The 400 year history of this relationship begs larger questions about historical uses of rapeseed.

III. The British Agricultural Revolution

Yet despite the frequent reference to *B. napus* in the historical botanical and agricultural literature, historians have widely neglected its impact on eighteenth century soils. F. L. M. Thompson remains the only historian that I have found who studied Brassica oil seed meal tillage as a form of improvement, however as he published years before modern researchers outlined pathogen suppression mechanisms, his work does not consider such contributions to the historical landscape.[51] While arguing that green manure innovation drove a Second Agricultural Revolution in the early to mid-nineteenth century, Thompson neglects earlier phases of technological development and fails to consider the economic and environmental importance of *B. napus* in the seventeenth and eighteenth centuries.

[51] F. M. L. Thompson, "The Second Agricultural Revolution, 1815-1880," *The Economic History Review* 21, no. 1 (1968).

Eric Kerridge redefines *The Agricultural Revolution* to include early seventeenth century innovation, yet he attributes no particular environmental benefit to rapeseed. While he argues that seventeenth century advances like crop diversification, swamp drainage, foddering, and convertible husbandry were equally important to the late eighteenth-century enclosures and rotations, Kerridge mentions rapeseed only in passing when listing series plantings and crop inventories.[52] We learn that rapeseed meal was used as a form of green manure, but so were a long list of other inputs—including clothing and even worn shoes. The tillage of farm recyclables is presented as a form of agricultural improvement, but ultimately rapeseed is a generic form of farm waste worth little more than other recyclables.[53]

Mark Overton is also scant with his coverage of rapeseed when re-establishing the British Agricultural Revolution as a late-eighteenth and early nineteenth century process. He includes rapeseed in only one paragraph and a chart in his 1985 paper titled *Diffusion of Agricultural Innovations in Early Modern England: Turnips and Clover in Norfolk and Suffolk, 1580-1740*. Though his analysis of probate inventories dates rapeseed to the English landscape as early as 1588, is not clear whether Overton considers rape or coleseed to be a form of improvement, and his chart, which plots distributions of crops from 1628 to 1640, only confirms where rapeseed was grown. [54] It is likely the plant was more widely distributed; probate inventories often excluded fallow fodders, meadow, and permanent pasture as these crops could not be cut, harvested, or stored in a barn.[55]

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[52] Eric Kerridge, *The Agricultural Revolution*, 1968, p. 26, 27, 29, 121, 137, 196, 236, 237 (rapeseed-cake), 239, 277, 289, 290, 298, 302, 303, 304, 306, 310, 322, 327, 329, 323, 346, 347, 348, 356, 241.
[53] Eric Kerridge, *The Agricultural Revolution*, 1968, p. 241.
[54] Mark Overton, *Diffusion of Agricultural Innovations in Early Modern England: Turnips and Clover in Norfolk and Suffolk, 1580-1740,* 1985, p. 209.
[55] For the exclusion of meadow and fallow from probate inventories see Stephen Broadberry, *British Economic Growth, 1270-1870*, 2015, p. 84; To verify fallow and meadow plantings of rapeseed see Eric Kerridge, *The Agricultural Revolution*, 1968, p. 29, 137, 238, 277, 348.

Similarly, Joan Thirsk, remains the only scholar to integrate *Brassica napus* (rapeseed) into an economic history of seed and crop introductions. Yet as she considers rapeseed to be one of many alternative crops that slowly diversified English production, she does not dedicate much wordcount to *B. napus* and fails to consider its unique environmental benefits to the soil.[56] Rapeseed dust is only briefly mentioned as a form of fertilizer in the book *Farm Production in England 1700-1914* by Michael Turner, John Beckett, and Bethanie Afton.[57] Finally, Harold W. Brace located more than 600 nineteenth-century seed crushing mills, and he believes that many served to primarily crush *Brassica napus* into oil.[58] However Brace does not delve deeply into the environmental impacts of the oil crushing industry.

Unlike the American Revolution or the French Revolution which can be described in terms of economic and political change that occurred within some discrete range of time, the defining chronology and structural features of the British Agricultural Revolution are largely questions of the ontological categories defined by modern historians rather than intrinsically discrete temporal patterns described by period actors or events. Yet while historians differ in their chronological and technological models of the British Agricultural Revolution, they each agree on the importance of nitrogen fixation from legume introductions and the increased cycling of nitrogen from the manure of larger herds supported by foddering innovation. In fact, the importance of nitrogen is one of the only common points of agreement in the historiography of the British Agricultural Revolution. With the exception of Joan Thirsk, who both avoids the question of nitrogen and the use of the word "revolution" in favor of long-term studies that span

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[56] Joan Thirsk, *English Peasant Farming; the Agrarian History of Lincolnshire from Tudor to Recent Times* (London: Routledge & K. Paul, 1957); Joan Thirsk, *Alternative Agriculture: A History from the Black Death to the Present Day*. *The Rural Economy of England : Collected Essays* (New York : Oxford University Press, 1997).
[57] M. E. Turner, J.V. Beckett, and B. Afton, *Farm Production in England 1700-1914* (Oxford University Press, UK, 2001), p. 87, 101.
[58] W. Brace, *History of Seed Crushing in Great Britain*, 1960, p. 99-158.

many centuries of change, most of the historiography is dominated by debates over nitrogen fixation and cycling.

Thompson's manure revolution of bones, potash, and flax meal was thought successful for increasing nitrogen, though he did not specifically extend this benefit to *B. napus*.[59] The model of a seventeenth century Agricultural Revolution developed by Kerridge is cited for its reliance on nitrogen as a mechanism of soil improvement, and though Kerridge focuses more on historical practices than their chemical and biological impacts, he describes the problem of stagnation in the grass pastures and the benefit of ploughing and planting "sod impregnated with droppings and urine."[60] Over generations of dedicated land use, the historical village grazing commons became saturated while the fixed nature of arable strips depleted soils. New fodders and manures, as well as the ploughs, drills, and horse-hoes that facilitated more rapid rotations, allowed farmers to convert pasture and tillage more rapidly. Such technologies also supported larger herds and thus greater manure inputs.

Robert Allen accepts this model, but advocates for the importance of nitrogen fixing fodders above manure, which merely recycled the nutrients taken from the soil back to the field.[61] Allen agrees with Kerridge on the importance of the early seventeenth century in economic transformation, but focuses on the role of the emerging yeomanry and landed gentry in accruing wealth from good harvests to invest in technological development. In contrast, it was the landlord elites who profited from late eighteenth century enclosure, and they seem to have

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[59] Thompson, "The Second Agricultural Revolution, 1815-1880," p. 68, 70.

[60] On p. 62 Clark writes that the Kerridge model is premised on nitrogen theory. Gregory Clark, "The Economics of Exhaustion, the Postan Thesis, and the Agricultural Revolution," *The Journal of Economic History* 52, no. 1 (1992). Eric Kerridge, "The Agricultural Revolution Reconsidered," *Agricultural History* 43, no. 4 (1969): p. 200-2, 07.

[61] Robert Allen, C., "The Nitrogen Hypothesis and the English Agricultural Revolution: A Biological Analysis," *The Journal of Economic History* 68, no. 1 (2008): p. 202.

been more interested in larger country houses and luxury.[62] In this model, nitrogen becomes the little-known hero of the middling classes.

Yet nitrogen accumulation is also a complex question related to land use practices, according to Clark, who presents evidence that hay cut over the generations from long-term pasture may have depleted the soil of nutrients.[63] Pastures may or may not have become saturated, even if arable tended towards depletion. Based on the work of M. M. Poston, who argued that medieval cultivators understood the benefits of land conversion but refused to adopt this method, Clark demonstrates that shorter leases, uncertain prices, labour demand, and greater social and political upheaval increased the medieval rate of discount of future benefits of livestock husbandry.[64] Nitrogen was not cycled in the landscape because the lordship as well as any tenant farmers who enjoyed early private lease rights faced a much greater opportunity cost when converting land to pasture or dedicating long-term planting time and seed costs to fodder for larger herds. Revenue from grain was more immediate, and this depleted soils. Clark writes "My alternative explanation for the cause of the agricultural revolution suggests that many of the gains may have stemmed from a decline in the rate of return in agriculture, leading to an increase in the stock of nitrogen farmers kept in the soil."[65]

In contrast, Mark Overton re-established the traditional chronology of the British Agricultural Revolution by highlighting the importance of fodders, which though introduced much earlier only became planted on a larger number of acres in the mid nineteenth century.[66] "We can, however, be fairly certain that the 'limiting factor' to cereal growth before the early

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[62] Robert C. Allen, *Enclosure and the Yeoman* (Oxford : New York: Clarendon Press ; Oxford University Press, 1992).
[63] Clark, "The Economics of Exhaustion, the Postan Thesis, and the Agricultural Revolution," p. 66-7.
[64] Ibid., p. 61, 75-6.
[65] Ibid., p. 79.
[66] Mark Overton, "Re-Establishing the English Agricultural Revolution," *The Agricultural History Review* 44, no. 1 (1996): p. 8, 9, 11.

nineteenth century was the supply of nitrogen," wrote Overton. [67] He otherwise downplays the importance of technology development by questioning the chronologies and models of innovation. He writes:

> It has been shown that 'Turnip' Townshend was a boy when turnips were first grown on his estate…. Although Coke of Holkham was a great publicist (especially of his own achievements), some of the farming practices he encouraged (such as the employment of the Norfolk four-course rotation in unsuitable conditions) may have been positively harmful.[68]

Instead it was the overall improvement of husbandry practices during the mid to late nineteenth centuries that increased cereal yields. Fodders may have been widely dispersed in the eighteenth century, but the percent of acreage planted in improving crops only rose over the course of the nineteenth century.[69] Output productivity followed this same course.[70]

I do not dismiss the importance of nitrogen in crop production. However the models of the British Agricultural Revolution rarely dig so deeply into any historical technology to sufficiently evaluate its net environmental impacts. Clover and other fodder introductions caused soil exhaustion.[71] Larger herd sizes increased the risk of over-grazing even while offering soils greater manure inputs. Foddering and rotations offered only a slow and cumulative benefit by increasing soil fecundity over many years. [72] Similarly, convertible husbandry sometimes increased soil molds and grass deterioration as it was difficult to establish regenerating meadows for long-term grazing and equally hard to prepare sod for arable tillage

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[67] Ibid., p. 11.
[68] Mark Overton, "Agricultural Revolution? England, 1540-1850," in *New Directions in Economic and Social History*, ed. A. Digby and C.H. Feinstein (Palgrave Macmillan, 1989), p. 10.
[69] Overton, "Re-Establishing the English Agricultural Revolution," p. 9, 11.
[70] *Agricultural Revolution in England : The Transformation of the Agrarian Economy, 1500-1850*, Cambridge Studies in Historical Geography. (Cambridge ; New York: Cambridge University Press, 1996), p. 64.
[71] Kenneth Pomeranz, *The Great Divergence : Europe, China, and the Making of the Modern World Economy*, Princeton Economic History of the Western World (Princeton, N.J.: Princeton University Press, 2000), p. 198
[72] Ibid., p. 198, 210.

without large amounts of labour. For the average farmer, attempts at convertible husbandry ran the risk of environmental deterioration and financial loss.[73]

Increased nitrogen fixation and cycling were not the only benefits of technological change. For example, while seed drilling and horse-hoeing may have increased the rate of foddering, these practices also supported deeper root formation and thus better access to a range of nutrients and water. As the over-all size and robust structure of crops improved, the agronomic system became more resilient to change. As it is impossible to test any ecophysiological variable in a historical landscape that no longer exists, *B. napus* serves as a window into the evolutions of designs that supported a wide range of changes in the soil.

The current project thus aims to move beyond any single environmental model in order to consider the larger advances in design that facilitated relationships between nutrient deposition, nutrient cycling, increased nutrient bioavailability, a more robust soil microbiome, soil pest and pathogen suppression, and other improved soil conditions. As the accumulation of nitrogen was indisputably a slow process in the generations before synthetic fertilizers, we must ask how the combinations of technologies integrated other improvements through the whole farm design. While rapeseed's unique capacity to suppress pests introduced an alternative environmental mechanism that would have had a profound impact even if the crop was grown at the small-scale, *B. napus* is most valuable as a historical study for its versatility as a design element. It was introduced at the large scale for oil crushing and served as a seed manure in the earlier seventeenth century before turnips, clover, Lucerne, Sainfoin, and the other fodders moved from botanical gardens to the field. As *B. napus* arguably pre-dates most of the defining innovations of the British Agricultural Revolution, it was a working part of the landscape ready for

[73] Eric Kerridge, *The Agricultural Revolution* (New York: A.M. Kelley, 1968), p. 200-08.

incorporation at the dawn of economic restructuring. We can thus use *B. napus* as an indicator of agronomic change through its incorporation into innovative technologies. More than the introduction of any new technology, how did their incorporation into diversified systems of integrated agriculture mark key transition points?

IV. Transforming the Commons

By tracing the evolution of the whole farm design, we can relate advances in privatization and capitalist farming to agricultural progress. The bird's eye view of the eighteenth century landscape included an increasing number of privatized pastures managed under longer leases held by tenant farmers. Some of these fields were rented by capitalist farmers after Parliamentary Enclosure opened common grazing land for larger-scale production. Other privatized farms were secured by an emerging yeomanry as early as the Black Plague, the Reformation, the English Civil War, when successive waves of enclosure followed labour scarcity and population decline, the dissolution of Catholic monastery farms, and political land grabs aimed at expanding parliamentarian and protestant Commonwealth interests. Privatized supported co-operative ventures and combined capital between the landlord and tenant to drain marshes and improve soils.[74] However at least by the mid-eighteenth century, if not earlier, some privatized leases also imposed limitations that prohibited more than two successive cash crops in a row to prevent soil exhaustion. Fallowing, green manuring, and land conversion between use types were required and sometimes prohibited.[75]

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[74] Susanna Wade Martins and Tom Williamson, "The Development of the Lease and Its Role in Agricultural Improvement in East Anglia, 1660–1870," *The Agricultural History Review* 46, no. 2 (1998), p. 127-128.
[75] Ibid., p. 33.

It turns out that rapeseed is one of the few crops noted by name in Midlands leases. A lease from Warwick dated January 03, 1756 is emblematic for charging additional rent of five pounds for the conversion of meadowlands into rapeseed or other oilseeds. The lease also requires summer fallowing with clover, especially if more than 140 acres was converted to tillage.[76] Similar leases signed March 05, 10, and 26, 1753 for about 80 pounds similarly charged additional rents of five pounds for acreage planted with rape.[77] According to other leases from the same county, by April 1790 the price had jumped to "ten pounds for each and every acre of the said premises hereby demised… to be sow with rape hemp flax, or woad." This fee was charged in addition to the yearly rent of 169 pounds.[78] A second lease from 1790 signed August 31 charged ten pounds an acre above the rent of 150 pounds and 10 shillings for land sown with "woad, weld, rape, hemp, or flax or hay seeds to make oil or for any part of the said premises which shall be ploughed tilled and managed contrary to the covenants for management hereinafter contained…."[79] This same month, the leaseholder Henry Christopher Wise signed at least three additional leases with the same terms charging ten pounds in additional rents for the "ploughing, digging, breaking up, sowing, converting into having or using in tillage or gardening or sowing with woad, weld, rape, hemp, or flax…"[80]

[76] Watts William and Wise Henry, "Lease by Henry Wise to William Watts, of Warren Farm in Moreton Morrell," in *Waller Family of Woodcote* (Warwickshire County Record Office, 1756).
[77] John Buckerfield and Matthew Wise, "Lease by Matthew Wise to John Buckerfield, of a Messuage and Several Closes of Land at Lillington," in *Waller Family of Woodcote* (Warwickshire County Record Office, 1753). Thomas Webb and Matthew Wise, "Lease by Matthew Wise to Thomas Webb, of a Messuage and Several Closes of Land at Lillington," in *Waller Family of Woodcote* (Warwickshire County Record Office, 1753).
[78] William Birch and Henry Christopher, "Lease by Henry Christopher Wise to William Birch, of Woodloes Farm and Land in Woodloes," in *Waller Family of Woodcote* (Warwickshire County Record Office, 1790).
[79] Henry Christopher Wise "Leases by Henry Christopher Wise to Thomas Birch, of Woodloes House and Farm in Woodloes," in *Waller Family of Woodcote* (Warwickshire County Record Office, 1790).
[80] Henry Christopher Wise, "Lease by Henry Christopher Wise to John Ledbrook, of a Messuage and Land in Lillington," in *Waller Family of Woodcote* (Warwickshire County Record Office, 1790). Thomas Webb and Henry Christopher Wise, "Lease by Henry Christopher Wise to Thomas Webb, of a Farm in Lillington," in *Waller Family of Woodcote* (Warwickshire County Record Office, 1790).

It is noteworthy that the Wise family paid twice as much to grow rape by the end of the eighteenth century. In January of 1795 an additional rent of 10 pounds per acre for rape plantings was charged to Edward Willes. If woad, weld, rape, or hemp were planted, there was an additional 460 pounds charged in rent per year.[81] The extra charge for planting *B. napus* may reflect the increasing commodity value of oilseeds in the late eighteenth century. In any case, it is remarkable to find rapeseed directly mentioned in period leases as most land indentures and legal agreements do not detail the crops that might have been grown. However as this study will show, the integration of *B. napus* into diverse temporal and spatial designs highlights the long term sustainability made possible by the greater autonomy that privatized leases represent.

In contrast, on English common fields the large-scale planting of rapeseed would have required the reorganization of land and thus labour.[82] The common fields of England were neither open to individualization nor vote by farmers. Growers were held to strict lease terms when planting a strip of land in common fields or grazing a limited number of animals in common pasture for designated time periods.[83] They either purchased or were provided tools, seed, or manure obtained by the Lordship, estate, or parish in exchange for taxes and tithes. A successful farmer who dedicated more energy to his allocated strips might slowly accumulate the resources to order new seeds or to hire labour to implement a self-designed course, but as the ability to sell surplus also depended on local practices orchestrated and protected by the

[81] Edward Wiles and Richard Court, "Lease from Year to Year by Reverend Edward Willes to Richard Court of Land in Newbold Comyn and Tenements and Land in Leamington Priors," in *Waller Family of Woodcote* (Warwickshire County Record Office, 1795).

[82] For an exploration of the emergence of wage labour in the English agricultural sector, see: R. A. Bryer, "The Genesis of the Capitalist Farmer: Towards a Marxist Accounting History of the Origins of the English Agricultural Revolution," 2006; J. D. Chambers, "Enclosure and Labour Supply in the Industrial Revolution," *The Economic History Review* 5, no. 3 (1953).

[83] J. M. Neeson, *Commoners : Common Right, Enclosure and Social Change in England, 1700-1820*, Past and Present Publications (New York: Cambridge University Press, 1993), p. 117-8, 87, 320; Eric Kerridge, *The Common Fields of England* (Manchester, UK ; New York : New York: Manchester University Press ; Distributed exclusively in the USA and Canada by St. Martin's Press, 1992), p. 9-11, 31, 83, 90.

Lordship, it often took a larger collection of small, arable family strips to produce enough oats or wheat for price negotiation. Resources were consolidated to ensure food security and protect surplus, and this gave rise to customary practices that determined crop choice and planting practices. It would have been difficult to integrate even a few cows into a small, arable strip as neighboring sites were producing crops that cattle might destroy. Hedges were the most common land division, and these required large investments of labor as well as rights to modify the property.[84] And if a farmer integrated cattle onto his strip, he might have no other plot on which to produce family food in the years when the site was regenerating through forage.

Thus, common fields continued to be managed through traditional rounds that ensured everyone planted the same cereals and grazed in the designated areas. Often the entire village marled their multiple narrow strips strewn across the ridge-and-furrowed landscape at the same time and planted the same crops. In other geographies, the Saxon three course required that communities rotated plantings and animals so that one field served as arable, one as grazing, and one as fallow. This practice may have been adopted on early leased lands, though without the requirement, some farmers on shorter leases might have opted to plant the fallow cycle. New crops like rapeseed thus required innovation in temporal and spatial cultivation designs, adequate acreage to produce surplus, regional diversification to support a localized economy of seed, cereal, and livestock sale or trade, and both the lease rights to improve upon the historical practice and local access to a variety of imported or locally grown seeds. Though enclosure was not without controversy in England, it allowed some farmers the freedom to test new winter feed solutions and customize design schematics with rape, cole, and turnips.[85]

[84] *The Common Fields of England*, p. 17, 95-6.
[85] Allen, *Enclosure and the Yeoman*.

More than innovators of crop technology, the British were integrators of multiple technologies because privatized leases allowed individual farmers to select and combine technologies on a small-scale, site-specific basis and profit from the fruits of their labour.[86] If Britain made any profound contribution by exceeding European farming practices, it was not by developing *B. napus* or any other husbandry—to the contrary, most fodder and mechanical technologies were imported from the continent and re-designed in England's moist, cool, fodder-friendly environment. *B. napus* was no exception and was introduced to England through waves of protestant immigration in the late sixteenth century.[87] A new rape oil milling design was imported from France in the early seventeenth century, and merchants sought patents to crush rapeseed for soap and textile finishing.[88]

England's maritime climate was ideal for *B. napus*, turnips, clover, and other fodder crops. In contrast, Patrick Karl O'Brien argued that "fodder crops of all kinds did not thrive in the arid conditions characteristic of Mediterranean France."[89] Cereal production may have expanded into areas that were environmentally unsuitable, but even in the 'grain belts' of France near Paris and Beauce, crops like olives, vines, and drought tolerant fruits and vegetables composed a portion of the agricultural economy. These drought tolerant plants that flourished in Southern France did not restore nitrogen to the soil because they did not support the rotation of

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[86] Bryer, "The Genesis of the Capitalist Farmer: Towards a Marxist Accounting History of the Origins of the English Agricultural Revolution."

[87] Thirsk, *Alternative Agriculture: A History from the Black Death to the Present Day*, p. 72-5.

[88] *The Rural Economy of England : Collected Essays*, p. 299; Sovereign England and Wales and King of England James I, "James, by the Grace of God, King of England, Scotland, France, and Ireland, Defender of the Faith, &C. To All to Whome These Presents Shall Come, Greeting Whereas Our Welbeloued Subject, Benedict Webbe, of Kingeswood, Clothier, Hauing in His Trauell, Obserued a Kinde of Oyle to Bee Made of Rape-Seede.," (London :: F. Kingston Ann Arbor, MI Oxford (UK) :: Text Creation Partnership, 1624); Joan Thirsk, *Economic Policy and Projects : The Development of a Consumer Society in Early Modern England* (Oxford: Clarendon Press, 1978), p. 71-4. *English Peasant Farming; the Agrarian History of Lincolnshire from Tudor to Recent Times*, p. 30, 222, 300.

[89] Patrick O'Brien is faculty at the London School of Economics. Patrick Karl O'Brien, "Path Dependency, or Why Britain Became an Industrialized and Urbanized Economy Long before France," *The Economic History Review* 49, no. 2 (1996): p. 220-23.

livestock. Perhaps this is why the grain-growing regions failed to innovate rotation practices. George C. Comninel argued that mid-to-late eighteenth century French agriculture was astonishingly untouched by the improved farming which had swept England over the previous century.[90] "Indeed, ignoring the new implements and crops of the agricultural revolution, not even the most important techniques that dated back centuries in English practice—particularly convertible, or up-and-down husbandry—were employed in France, except as the special projects of Anglophile agronomists," wrote Comninel.[91] In the mid-eighteenth century, French economist Francois Quesnay described that only wealthy farmers could afford horses and new ploughs, which were much faster but cost more overall than traditional oxen-drawn ploughs due to the depletion of the horses value in old age.[92] Oxen were eventually sold to the butchers, though they were slower and spent more time grazing so that farmers needed to have in pasture 12 oxen to do the work of four kept horses.[93] Many French peasants could not find work and were reduced to eating oatmeal and buckwheat because they could not wait for two years to plant the rotations needed for a crop of wheat.[94] Though rural French producers and sharecroppers made small-scale advances in traditional technologies, and this increased trade between towns, such advances were easily reversible due to changing market conditions.[95] Such trends in land tenure may have favored a larger abundance of smaller farms through the late sixteenth, seventeenth, and early eighteenth centuries in key growing regions like Île-de-France.[96] Though

[90] George C. Comninel is faculty of Political Theory in the Department of Politics at York University, Canada.
[91] George C. Verfasser Comninel, *Rethinking the French Revolution: Marxism and the Revisionist Challenge* (1987), p. 189.
[92] F. Braudel and S. Reynold, *Civilization and Capitalism, 15th-18th Century: The Structure of Everyday Life*, vol. 1 (University of California Press, 1992).
[93] W. A. Eltis, "Francois Quesnay: A Reinterpretation 1. The Tableau Economique.," *Oxford Economic Papers* 27, no. 2 (1975): p. 171.
[94] Ibid., p. 170.
[95] Stephen J. Miller, "The Economy of France in the Eighteenth and Nineteenth Centuries: Market Opportunity and Labour Productivity in Languedoc," *Rural History* 20, no. 1 (2009): p. 2-4.
[96] Ibid., p. 4.

large farms greater than 120 acres dominated 40% of the landscape in the eighteenth century, labour productivity may have stagnated due to war, heavy taxation, and labor-intensive forms of agriculture that supported population growth without significant increases productivity.[97]

England tended towards slightly larger farms and the middling classes maintained hold of a larger percentage of land, though as we will show later in this work, some farmers succesfully supported convertible rotations with small herds on fewer than ten acres with the help of *B. napus*.[98] Acidic soils were also less of a problem in England and greatly helped by "regular dressings of marl and lime which facilitated the conversion of manure into nitrogen and amended the composition of the soil in ways hospitable to the cultivation of root crops, particularly turnips, which could then be fed to animals in order to produce more manure," wrote O'Brien.[99] Thus, by the nineteenth century, new fodder integration allowed British farmers to boast 156 units of horsepower equivalents per 1,000 hectares of arable at a time when France struggled to replenish soils with only 36 units.

This is why a revised economic model of convertible husbandry must move beyond questions of fodder diversification and the chronologies of introduction and adoption in order to explore the patterns of localized, site-specific British field design innovation. To the extent that it was England's climate that supported the localized integration of fodders on increasingly larger farms, it is important to understand how fodder choices and temporal and spatial plantings different by soil type and growing conditions. To the extent that economic changes supported class integration in the form of larger farms and longer leases, how did farmers match the best

[97] Ibid., p. 4-9.
[98] Ibid.
[99] O'Brien, "Path Dependency, or Why Britain Became an Industrialized and Urbanized Economy Long before France," p. 220-21. O' Brien argues that it was nineteenth century British farmers who boasted 156 units of horsepower equivalents (livestock) per 1,000 hectars of arable while France struggled to replenish soils with only 36 units, and this success was due to turnips and other fodder species combined with convertible husbandry.

fodders to the local climate as the scale of agriculture changed? In fact, fodder technology innovation may have stagnated during the early phase of the seventeenth century introduction in part because farmers lacked the spatial and temporal strategies needed to sustain larger herds needed for manure inputs. It is not that new fodders paved the way for convertible husbandry, but rather that early convertible designs and small increases in herd size primed the system for larger-scale plantings of *B. napus* and other fodders. This, in turn, supported greater herds, more manuring, and a better soil quality for additional crops of animal and human food. This dissertation thus explores the ways in which farmers adapted to the diversity of microclimates and soil types in England, thus initiating a slow positive feedback loop in which gains in agricultural development improved soils for new fodders.

V. Chapter Summaries

My work is not a revival of a mythical golden age of agriculture. Not all early modern improvement technologies were sustainable, and even the Brassicas could be exhausting. But just as modern science can inform our interpretation of historical technologies, the long course of English agricultural improvement can suggest new technologies to test with modern science. My goal is to understand the macro and field-level constraints of the highly effective historical Brassica seed meal technology as it was paired with other important improvements like paring and burning and bone meal to contribute an over-all benefit to the soil. I hope this will inspire researchers and farmers to experiment with similar pairings of seed meal tillage and other historical techniques in order to boost the total benefits to the soil.

Instead this dissertation secures a platform for the remaking of age-old practices that can potentially perform with greater efficiency thanks to our different scientific and engineering capabilities. Despite the discontinuities of empire, industrialization, population growth and other ecological pressures, there is an enormous gap between the preindustrial world of 1800 and the post-industrial, modern agriculture that built upon the Green Revolution. To the extent that poor farming practices, emerging science, and less productive cultural environmental relationships created historical Malthusian traps and spurred dependency on colonial produced products, we can perhaps surpass the maximum yields per acre of the eighteenth century and create a system that locally produces a greater percent of the agricultural products needed for food and industry. Yet if our industrial farming practices are riddled with new environmental problems, and our scientific understandings reflect modern contextual constraints and biases, perhaps we can learn from the successes and failures of a period that produced highly potent technologies even before chemical pesticides and synthetic fertilizers could be shipped across the world in coal or oil powered ships.

CHAPTER TWO: Rapeseed in Agricultural Improvement

Tullian horse-hoed husbandry and seed drilling remain the hallmarks of the British Agricultural Revolution for representing the rapid advances in mechanical technologies that reportedly swept the countryside during the eighteenth century. Yet the agricultural improvers who published the best practices of the period were critical of Jethro Tull's rejection of rotation, fallowing, and foddering, and instead strove to apply new mechanized technologies in the field. It is well known that new planting innovations combined with the incorporation of alternative crops helped advance agriculture. But the use of mechanized technologies such as drills and horse hoes to plant alternative fodders in fallow fields for grazing was a practice that defied the Tullian gospel.

Using keyword searches and data mining, we trace *B. napus* through the hundreds of works on improvement to see the emergence of integrative designs that were small-scale, localized, and free of waste. Byproducts were incorporated into the soils as manures or into agricultural production as animal feed. This required alterations of the growing and production cycle so that byproducts and products had the right composition for environmental contributions. In contrast to Tull's intensified agriculture, improvers used the drill and horse-hoe to test rotations, green fallows, and new fodders for grazing to increase manure contributions.

B. napus was just one of the fodders incorporated. Yet along with the legumes, turnips, and various grasses, it serves as an ideal case study of the integration of agricultural and manufacturing practices. A broad survey of the archives uncovered evidence that *B. napus* was used by a range of classes, including tenant farmers who used the crop in a wide range of agricultural and industrial improvements. We thus trace the structure of integrated designs that localized the production of industrial raw material inputs, tailored growing practices to site-specific environmental parameters, and recycled outputs to minimize waste. Integrative design can serve as a lens for evaluating improvement plans, which were also driven by industrial goals and the pressure of economic development. Improvers designed milling, textile, and other factory systems to harness the local agricultural economy. Though this supported new orphanages, poor houses, and the printing of educational materials, the productivity of the landscape was ultimately the wealth of the people.

This chapter concludes with a history of the *B. napus* milling production chain. Oil mills harnessed local and imported seed, but crushed cake or meal was sold as feed and manure, thus returning byproducts to the land. The study of these community-scale economic designs uncovers solutions to the supply chain problems related to small, local producers in an economy that had no fossil fuel transportation. For example, rape mills also crushed shells and animal bones to make manure as well as flax to make linseed oil. Oilseed supplies ebbed and flowed due to site-specific rotations but did not stop production because the economy was predicated upon a diversified design that supported multiple inputs and recycled byproducts into the economy.

CHAPTER THREE: Rapeseed and Turnip Combining in Convertible Husbandry for Increased Land Use Efficiency

By studying fodder combining as an economic question, this chapter moves beyond the nitrogen thesis and the historiographic turnip-philia to present overlooked evidence that eighteenth-century farmers developed sophisticated spatial and temporal design strategies to integrate the *B. napus* plants often sown for oil crushing into field turnip agriculture for convertible husbandry. By data mining digitized improvement publications from the long eighteenth century, we find that many authors who celebrated turnips as the basis of the modern economy also practiced crop diversification with rapeseed for winter feed, green fallows, and fodder polyculture. Though turnips were critical to the success of convertible husbandry practices, which increased herd sizes and cycled manure into arable acres, many farmers preferred *B. napus* integration for its frost tolerance and compatibility with poor soils. *B. napus* oilseed plantings increased the reliable supply of winter turnip fodders while also serving as planted, cut and dried feed, and winter cake.

Rape was clearly planted for feed in the seventeenth century, and convertible husbandry designs can be traced to the Medieval and early modern periods. But in the eighteenth century, historical actors were knowingly incorporating these designs into a litany of site-specific land use plans that varied crops by soil structure and used planting and grazing strategies to increase herd size, enhance desired soil features, and overcome poor growing conditions. This illustrates how convertible husbandry designs slowly exceeded the simple turnip planting for feed in order to strategically manage an on-going regenerative cycle. The importance of bare fallow conversion to green rotations of *B. napus* or turnips is a hallmark example of an integrated system not only for the relationship formed between green manure, fodder, and animal manure, but also for the increase in land use efficiency made possible by this relationship.

Ultimately the increased nitrogen from larger herds is thought to have increased grain yields per acre per worker, and this served as a backbone of economic development for supporting a larger population without a proportionate increase in arable acres. The convertible design became reciprocally co-determined with fodder technology development by the end of the eighteenth century when fodder and livestock began a positive feedback loop. The increased livestock manure only bettered growing conditions, and the continued success of fodder provided for even larger herds. While England had previously known planted fallows and had long alternated grass and arable, it was in the eighteenth century that the percent of bare fallow diminished in favor of planted fallow and when the length of the fallow rotations shortened, thus supporting this relationship between fodder improvement and herd size.

CHAPTER FOUR: *Brassica Napus* in the Norfolk Rotation for Course Design Diversification

Rotation designs are often understood in terms of the temporal relationships formed between regenerative species and cash crops such as cereals. As the most commonly cited example, the Norfolk Rotation is defined by the incorporation of species like turnips, barley, clover, and wheat, though rye and oats are also noted by some historians. This chapter explores the use of *B. napus* in the proper Norfolk Rotation and in modified course designs, where it was harnessed as a fodder in place of turnips, grown as a substitute for clover, and planted as a cash crop in place of wheat at the end of a rotation designed to improve soil fecundity. By tracing *B. napus* through course designs, we see a greater diversity in the Norfolk Rotation that has been previously described in most literature. The temporal relationships formed between nitrogen-fixing clover, turnip fodders for increased animal manure, and the plantings of cereals, are thought to have determined the ability of soils to support ongoing plantings without long periods of fallow. The versatility of *B. napus* as a design element highlights the importance of emerging concepts of plant functional groups, which were not stable categories in the eighteenth and nineteenth centuries and reflected a wide range of concepts of plant-soil interactions.

This chapter also presents rare planting calendars found at the archives in the East Riding of Yorkshire to trace *B. napus* through multiple years on the same sites. Farmers not only lengthened temporal designs and incorporated alternative crops, but also interchanged species according to their performance categories. *B. napus* highlights the importance of plant functional groups to eighteenth and early nineteenth-century farmers, who thought in terms of a fodder, grass, and cash crop cycle. *B. napus* was substituted into each of these categories, which highlights the emerging structure of functional categories. Finally, though course plantings varied between geographies, even the proper Norfolk Rotation was modified by farmers to include up to eight courses and to include paring and burning. It is difficult to reconstruct the Norfolk from probate inventories and other period land and crop surveys, which were rarely repeated on the same site during multiple times of the year so as to show the use of all crops in the rotation. However rare planting calendars help elucidate the practice of the rotation from the recommended model.

Norfolk Rotation is touted for increasing soil nitrogen fixation through its incorporation of clover, yet it turns out that grasses were often substituted for the nitrogen-fixing crops. *B.*

napus was similarly used in this role, which suggests the potential for soil pest suppression benefits. It is unlikely that eighteenth and early nineteenth century farmers understood either of these mechanisms. Yet *B. napus* designs show that growers exploited rotations to meet the needs of local environmental constraints and to maximize yields.

CHAPTER FIVE: Rapeseed for Manuring to Fight Pests and Improve Soils

Though the *Oxford English Dictionary* limits the sixteenth, seventeenth, and eighteenth-century definitions of "manure" to dung compost or chemical top-dressing fertilizers, it is clear from period improvement manuals that farmers used the term to reference a wide range of other soil inputs ranging from woolen rags, sawdust, and green plants cut and ploughed into the soil.[100] It is thus important to move beyond animal contributions if we are to understand the environmental impacts of the manures that reshaped the soils of the British economy. This chapter shows that *Brassica napus* (rapeseed) meal tillage was used as a plant manure to increase soil nitrogen and suppress wireworm larvae of the common click beetle pest (*Coleoptera: Elateridae*). The maintenance of preferred oil concentrations in *B. napus* manure as well as the recommended rates of manure application were compiled through data mining and key word searches of the digitized rare books and articles published to document the best practices for agricultural improvement in the eighteenth century.

This case study is among the first to explore the role of pest suppression improvements in the British Agricultural Revolution and to illustrate the relative net environmental impacts of Brassica technologies. For its resistance to molds, *B. napus* manure may have been a particularly important tool for use on the large spans of wetlands and water logged soils drained during the

[100] Oxford English Dictionary, "Manure, N," in *Oxford English Dictionary* (Oxford University Press, 2020).

eighteenth century. In another example, as agricultural intensification and larger scale monoculture are linked to increased pest problems, *B. napus* manures may have also been an important tool in maintaining yields on lands where ongoing rotations replaced bare fallowing and grass leys. *B. napus* is by no means the only pest treatment found in eighteenth-century agricultural manuals. By the end of the long eighteenth century, soda, potash, salt, sawdust, and even chlorine were sometimes used to kill worms, pests, and weeds, though sulfur, chrysanthemum extract, and mercury residues date to the ancient world.[101] It is thus important to reconsider the importance of *B. napus* for worm and pest suppression in the specific case studies of poor soil conditions that were improved for cash crops like oats, turnips, and wheat.

[101] C. W. Johnson, "On the Destruction of the Wireworm," *Working Farmer* 3, no. 2 (1851): p. 38; John Unsworth, "History of Pesticide Use " International Union of Pure and Applied Chemistry http://agrochemicals.iupac.org/index.php?option=com_sobi2&sobi2Task=sobi2Details&catid=3&sobi2Id=31.

1.3 *Trail Through Rapeseed Field, Halsham, East Riding of Yorkshire, 2018,* Amy Coombs.

CHAPTER TWO: Rapeseed in Agricultural Improvement

I. Introduction

By the nineteenth century, horse-hoeing husbandry and seed drilling had become emblematic examples of the mechanical progress that concluded England's dark age of agriculture. Though Jethro Tull was not the first to pull a hoe with a horse or attempt a drill-like mechanism for planting, the Tullians were among the first to insist on deep ploughs to turn manure twelve inches into the earth and to plant crops in a nearly perfect straight line so that horse-hoes could clear weeds on either side of the crop row. This technique was thought to reduce or entirely remove the need for fallowing and manuring. "The ingenious Mr. Jethro Tull was the first Englishman, perhaps the first writer, ancient or modern, who has attempted to reduce agriculture to certain and uniform principles…" wrote a dedicated Tullian with the initials D. Y. in his October 18, 1764 article *On the Improvements in Agriculture*.[1] Tull's machines supported faster planting by replacing the expensive labour that limited widespread experimentation with new crops. By the end of the century, Tull was glorified for his mechanical innovations as far away as Europe and the Americas. According to an article that appeared in the Southern Review "From the time of the ancient Romans to the book of Jethro Tull, we know of little that has been added to the theory or practice of Agriculture that deserves to mark an era in its history either as an art or a science."[2] The article encouraged the application of Jethro Tull's deep ploughing and seed drilling to the cotton fields of South Carolina.[3]

[1] Y. D, "On the Improvements in Agriculture," (1764).
[2] Southern Review, "The Horse-Hoeing Husbandry: Or, a Treatise on the Principles of Tillage and Vegetation, &C. The Manures Most Advantageously Applicable to the Various Sorts of Soils, &C./Elements of Agricultural Chemistry. A New System of Cultivation, without Lime or Dung, or Summer Fallows; as Practised at Knowle Farm, in the County of Sussex," *Southern Review* (Charleston, SC) 1, no. 1 (1828), p. 49.
[3] Ibid., p. 59.

Tull was even controversial during his own time for arguing on behalf of successive plantings without rotation and for claiming credit for a long history of mechanical innovation. "Jethro Tull was something of a crank and not the first person to invent a seed drill," wrote Overton.[4] E. R. Wicker similarly noted in his essay cheekily titled "Jethro Tull: Innovator or Crank?," that historians of English agriculture have long begun studies of agricultural progress with Tull's 1731 publication on horse-hoeing even though "there seems to be less agreement concerning either the specific principles of Tullian husbandry or the validity of those principles."[5] Tull perhaps made his biggest blunder by insisting that tillage was a substitute for fertilizer and manure and that air and water were all that were needed to replenish the soil. For Tull, soil was the only food of plants.[6] Though he admitted that abandoning manures without increasing tillage could be fatal, his ideal farming had no place for manures.[7] By the end of the eighteenth century, the improvers had come to favor rotation with drilling but viewed the Tullians as heretics.[8] At best, historians like Laura Sayre only partially redeem Tull for his popularization of labour-saving technology and for sparking controversial debate over the very issues still with us today—rotation costs versus input costs, till or no till, profits or sustainable yields.

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[4] Mark Overton, "Agricultural Revolution? England, 1540-1850," in *New Directions in Economic and Social History*, ed. A. Digby and C.H. Feinstein (Palgrave Macmillan, 1989), p. 10.

[5] E. R. Wicker, "Note on Jethro Tull Innovator or Crank?," *Agricultural History* 31 (1957): p. 46.

[6] In the *Southern Review* we read "The great facility afforded of stirring up the earth about the roots of plants, thus enabled the soil, in dry weather, to imbibe more easily the dews of the atmosphere…..and of effectually killing weeds, thereby rendering a fallow useless—of applying manure more economically—and of saving seed—are arguments in favor of the drill and horse-hoe, so substantial, that no practice of a common farmer (who can seldom be brought to look farther than the beam-end of his plough) ought to be opposed to it;" "The Horse-Hoeing Husbandry: Or, a Treatise on the Principles of Tillage and Vegetation, & C. The Manures Most Advantageously Applicable to the Various Sorts of Soils, &C./Elements of Agricultural Chemistry. A New System of Cultivation, without Lime or Dung, or Summer Fallows; as Practised at Knowle Farm, in the County of Sussex," p. 53-4.

[7] T. H. Marshall, "Jethro Tull and the "New Husbandry" of the Eighteenth Century," *The Economic History Review* 2, no. 1 (1929), p. 45.

[8] Laura B. Sayre, "The Pre-History of Soil Science: Jethro Tull, the Invention of the Seed Drill, and the Foundations of Modern Agriculture," *Physics and Chemistry of the Earth* 35, no. 15 (2010), p. 855-57.

This chapter traces the blasphemous improvements that rejected Tullian theory by using the horse-hoe and seed drill to plant the very fodders, fallows, manures, and rotations that Tull dismissed. The golden *Brassica napus* (*B. napus*, rapeseed) grown for its oil-rich seed to crush at the mills was one of many crops that became more widely drilled, horse-hoed, and planted on deep-tilled soils during the long eighteenth century. While *B. napus* has received less attention in the historiography of the British Agricultural Revolution than clover and turnips, which were also planted using Tullian innovations, the crop offers an ideal case study for its multi-functional contributions to the agronomic system. The planting of new fodders and feeds like turnips and swedes was particularly labour intensive, and required hand seeding, hoeing, and sometimes transplanting to maintain the right spacing between plants. *B. napus* was no exception, but is particularly interesting as a case study because it was both planted with a drill and horse-hoe and distributed as a cake manure by the same method. Crushing *B. napus* seed for oil produced powdery husks of cake and meal, and these served as a potent manure for turnips and other fodders as well as a pest control strategy applied to soils infested with wireworm. Not only was *B. napus* drilled for oilseed crops and for fodder, fallow, or rotation, but its meal and cake were applied to the soil in much the same fashion.

Examples of seed drilling for cropping with B. napus abound. In 1809 William Fordyce Mayor wrote that in Berkshire rape was broad cast sown in June at the rate of two pounds of seed per acre and drilled so that rows were twelve or fourteen inches apart.[9] Due to the better spacing of the plant, Henry Eustasius Strickland in the East Riding of Yorkshire believed that the rape grew stronger when drilled. "I have drilled rape in rows at a distance of from eighteen to twenty

[9] William Fordyce Mavor, *General View of the Agriculture of Berkshire: Drawn up for the Consideration of the Board of Agriculture and Internal Improvement.* (Richard Phillips, Bridge Street, Blackfriars, 1809), p. 215-19.

inches and found it to answer the purpose here alluded to by throwing out a larger top and consequently preventing it from growing hard and sticky…," he wrote.[10]

Other examples highlight the importance of *B. napus* drilling and horse-hoeing to the success of new fodders for herd expansion. In 1813 in the County of Elgin, Moray in Scotland, William Leslie described the role of drilling in the local oil economy when he wrote "In the same view it may be proper to mention a mill for making the oil of rape seed, which being a green and *drill hoed crop* would contribute to the fertilizing of the land to the spring food of cattle by the leaves and to their winter subsistence by the seed cake."[11] According to the *Annals of Agriculture and Other Useful Arts*, rape was also planted in the gaps between rows of drilled crops after the last horse-hoeing. This not only smothered the weeds "but afford[ed] a prodigious quantity of sheep-feed after the crops are reaped."[12]

Even if oilseed was worth the landlord's investment in labour for hand-hoeing and transplanting, the tenant farmer faced high opportunity costs to plant rapeseed for animal feed or fodder. This is because herds increased slowly and only improved manure contributions over the long term. It would take years for the extra labour and costs invested in foddering to result in healthier soils and higher yields than those obtained from bare fallowing or a three field rotation. There was little incentive to widely test new fodders because planting was too laborious without a drill and horse-hoe. The details of rate of application in terms of pounds of seed per acre generally varied based on the use of the field for fodder or oilseed, and whether crops reshot

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[10] Henry Eustasius Strickland, *A General View of the Agriculture of the East-Riding of Yorkshire*, ed. Agriculture Board of (York: Printed for the Author, (T. Wilson and Son), 1812), p. 139.
[11] William Leslie, *General View of the Agriculture in the Counties of Nairn and Moray: With Observations on the Means of Their Improvement*, ed. Board of Agriculture (R. Phillips, 1813), p. 436-7.
[12] Arthur Young, *Annals of Agriculture, and Other Useful Arts*, v. 46 vols., vol. v. 5, (London: Arthur Young, 1784), p. 281.

from a field grazed down by livestock depended on the season and length of grazing[13] Due to the complexities of these details, many eighteenth-century tenant farmers continued to graze smaller herds on the estate or parish commons until Parliamentary Enclosure. They otherwise might keep a few sheep on their orchard or other lands. As a result, the nutrient flows through the landscape were disintegrated. Over time pasture became over-saturated from manuring while also suffering from over-grazing. Meanwhile, arable plots became more nitrogen deplete due to the lack of manure input.

Based on examples of turnip and clover drilling, it is not entirely surprising that a plant like *B. napus* grown for fodder would be similarly planted, but this was only the beginning of the plant's story as an improvement technology. It turns out that the flakey *B. napus* meal and cake left from the oil press were also tilled as a manure directly into the seedbed with turnip. In the 1807 *Practical Agriculture, or A Complete System of Modern Husbandry* by R. W. Dickson, we learn that rape cakes brought into a powdery form by mills were spread by seed drill. Rape cakes were specifically applied in the ratio of a quarter of a ton to the acre with the powder distributed over planted turnip seed, and Dickson utilized seed drills to distribute both the planted seed and the crushed cake made of meal.[14] Buried in a footnote in the 1810 *General View of the Agriculture of Buckinghamshire*, St. John Priest detailed the use of the seed drill machine to spread oil-cake with turnips at a rate of one ton to six acres on the best turnip land. The authors wrote "….upon the land of an inferior quality, Mr. Coke uses only a ton upon three

[13] Richard Watson Dickson, *General View of the Agriculture of Lancashire, with Observations on the Means of Its Improvement* (Sherwood, Neely & Jones, 1815), p. 359-60.
[14] R. W. Dickson, *Practical Agriculture, or, a Complete System of Modern Husbandry : With the Methods of Planting, and the Management of Live Stock : In Two Volumes*, ed. R. W. Dickson, v. 2 vols., vol. v. 2 (London: Printed for Richard Phillips ... by R. Taylor and Co. ... 1805), p. 653.

acres: he first uses long yard manure as far as it will go, and then oil-cake."[15] Priest clarifies that the oil-cake is "generally made of rape, which having first been broken into small pieces, is sown broad-cast upon the land…" though "Mr. Coke drills oil-cake with turnips…".[16]

The drilling of crushed *B. napus* husks from the mill with turnip seed even inspired a modification to the machinery. Small cups were added to the seed drill to facilitate a separate pathway of delivery to the soil for the cake or dust. This allowed for different rates of application of manure and seed in the same run of the drill. Arthur Young described the use of the innovation in Norfolk in 1804 when he wrote "It contains alternate divisions with large and small cups for the delivery of both cake and seed into the same drills. In this way a ton does six acres instead of three or four in the common method."[17] By now Tull's innovation had undergone several modifications, and the agricultural reformer Thomas Coke recommended that a new drill-plough design be modified to "add to that machine an apparatus for sowing rape-cake-dust with turnip-seed…" wrote Young.[18] As an invention was already in use in the area, the patent holder Mr. Cook only had to procure an apparatus from another farmer to demonstrate the technology to Young during his trip to the Holkham Estate in Norfolk, now a historical landmark of agricultural innovation for Thomas William Coke's work to implement the Norfolk Rotation on tenant farms.

This chapter contributes to this history of innovation by situating *B. napus* in the new context of "integrated farming." The story of *B. napus* drilling moves beyond questions of the best practices as described in the above examples and highlights the development of a malleable

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[15] St. John Priest and Richard Parkinson, *General View of the Agriculture of Buckinghamshire Drawn up for the Board of Agriculture and Internal Improvement*, ed. Board of Agriculture (London:(London): Printed by B. McMillan, 1810), p. 276.
[16] Arthur Young, *General View of the Agriculture of the County of Norfolk* (G. and W. Nicol, 1804), p. 276.
[17] Ibid., p. 419.
[18] Ibid., p. 418-19.

relationship between plant and machine that could be applied at the small scale through localized design innovation in order to recycle byproducts from production back into the earth. Though the phrase 'integrated farming' was not used during the period and still lacks rigorous academic definition, the concept reflects a trend in the modern sustainable farming and building sectors and can serve as an analytic category for evaluating energy and nutrient exchanges in historical agronomical systems.[19] Integrated designs are developed through the formation of closed loop systems. First, production is localized so that raw materials like seed are grown and shipped closer to the site of use and consumption. For example, bark and saw dust left from timber milling might be used as a manure to grow food on site or sold to local farms as a mulch. Second, integrated designs create cradle-to-cradle organization so that outputs are either consumed or recycled as inputs. Finally, systems are combined so that one product feeds two production cycles and waste is more directly used as product. The temporal rotation of animals and fodder through arable land is a good example of design integration.

U.K. Behera and J. France describe linked systems in one of the few papers to propose integrated farming as an analytic category for comparing subsistence farming in India to the Western model of industrial agriculture.[20] In their case studies, waste or by-product utilization is

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[19] Though the permaculture movement does name 'integration' in its design principles, it is important that resource use is primarily a question of design. For example, site-specific observation of soils, sunlight patterns, and other features marks the begining of the process; All outputs are consumed or serve as inputs so that design produced no waste (e.g. zero waste); Designs move from observed patters to perceived details; Integration rather than segregation is key; Designs are smaller scale to meet the demands of local environmental conditions and to avoid big problems when mistakes are made. There are twelve total principles put forward by the founders of the permaculture movement. Also see the US Green Building Council's LEED standards for sustainable engineering design, which reference integrative design in the context of combining multiple energy saving systems into one building and observing whole systems. This contrasts with the implementation of protocols that might not work for every building. Also see the 'cradle-to-cradle' movement which achieves design integration in the form of waste recycling. Every output of a system is integrated into a different course of production unless it is consumed.David Holmgren and Richard Telford, "Permaculture Design Principles" https://permacultureprinciples.com/principles/. US Green Building Council, https://www.usgbc.org/education/sessions/leed-v4-integrative-design-process-4839891. Ecovia Intelligence, http://www.ecoviaint.com/r0505/.

[20] U. K. Behera and J. France, "Chapter Four - Integrated Farming Systems and the Livelihood Security of Small and Marginal Farmers in India and Other Developing Countries," *Advances in Agronomy* 138 (2016), p. 250-2.

not just about recycling but reflects the integration of farm subsystems such as livestock, diary, mushroom, wood product, grain, and vegetable production. As surplus is sold for profit, the economic incentive to minimize waste by using straw from mushroom production as cattle feed and manure preparation, poultry droppings for pisciculture for plankton growth, and manure for biogas generation creates additional subsystems of production such as compost, fish feed, and energy.[21]

While this establishes an integrated farm as a set of spatially, energetically, and economically linked systems that reduce pollution and increase diversification, Thomas Nemecek and his colleagues demonstrate that integrated farms are prone to use chemical and synthetic inputs even at reduced loads.[22] In his life cycle assessment of Swiss farming systems Nemecek distinguishes organic farms, which ban chemical-synthetic pesticides, and integrated farms that draw from "integrated pest management" to reduce chemical pesticides by introducing spiders or predators, using small-scale soil burns to kill pest eggs, creating forest islands in a field of mosaic plantings to break apart the pest breeding habitats, and other methods. "Integrated production (IP) emerged from integrated pest management but include all areas of the production system," writes Nemecek.[23] Diversified crop rotation, soil production during winter to reduce erosion and nutrient leaching, and equilibrated nutrient balance are among the features of integrated farming, according to Nemecek.[24] David Archer highlights similar benefits and problems, but adds to the definition of integrated farming a synergistic relationship between economic and spatial-temporal organization, including ally cropping, perennial cover cropping,

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[21] Ibid.
[22] Thomas Nemecek et al., "Life Cycle Assessment of Swiss Farming Systems: I. Integrated and Organic Farming," *Agricultural Systems* 104, no. 3 (2011), p. 218, 222. Behera and France, "Chapter Four - Integrated Farming Systems and the Livelihood Security of Small and Marginal Farmers in India and Other Developing Countries," p. 249.
[23] Nemecek et al., "Life Cycle Assessment of Swiss Farming Systems: I. Integrated and Organic Farming," p. 218.
[24] Ibid.

intercropping, crop-livestock integtation through rotation, and the better integration and use of animal manures.[25] In contrast, P. Vereijken describes integrated farming in terms of eco-system oriented, multifunctional agriculture.[26] However while each of these authors describe the spatial, temporal, and economic patterns of integrated farming in order to draw contrast with conventional and industrial methods, they stop short of defining integrated systems as an applied design framework. By using *B. napus* as an indicator of design, we can trace the features of integrated design in order to better understand green fallowing, winter feeds and fodders, land conversion, crop rotation, and plant manuring. When *B. napus* was combined with other low-toxic treatments and nutrient-building practices like animal grazing and manuring, clover for nitrogen fixation, and better tillage practices, the soil was over-all more healthy and better able to fight disease.

Industrial farms have broken these subsystem relationships.[27] Monoculture can span for thousands of acres, and farmers plant the same crops year after year. Animals are farmed at industrial dairies or livestock houses, which buy most of their feed off site. It is rare that a dairy farm with 2,000 cows or more would be located on the same site as grain production, in part because cows are traditionally kept under an open air barn and manure is held in holding ponds that are sometimes as large as seven or eight acres and release methane into the atmosphere. This separates the systems of livestock and grain production, and manure is treated as a waste rather than as a resource. Similarly, synthetic fertilizers are mined and pesticides and herbicides manufactured through processes that sometimes generate radioactive waste and other pollution.

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[25] David W. Archer et al., "Integrated Farming Systems," in *Encyclopedia of Ecology*, ed. Brian Fath (2019).
[26] P. H. Vereijken, "Transition to Multifunctional Land Use and Agriculture," *Wageningen Journal of Life Sciences* v. 50, no. 2 (2003): p. 172-3, 78; "A Methodic Way to More Sustainable Farming Systems," *Netherlands Journal of Agricultural Science* v. 40 no. 3 (1992): p. 211.
[27] Behera and France, "Chapter Four - Integrated Farming Systems and the Livelihood Security of Small and Marginal Farmers in India and Other Developing Countries," p. 251.

[28] Both the fertilizer, pesticide, and the wastes of manufacturing are transported long distances for use and disposal. The cumulative sum of synthetic fertilizer application has produced problems like the dead zone in the Gulf of Mexico.[29] Modern engineering systems often send byproducts from the mill or farm to the dump or let piles of waste rot because transportation costs to other farms and recycling centers are high and market values remain low for seed meals, dusts, grape crushing and fermented pulp. When these resources are used as a manure or compost starter, they are turned back into nutrients for local plants.

Integrative designs thus rely on qualitative measures of soil health because modern science has focused on engineering industrial systems while the tools need for site-specific soil microbial analysis remain cumbersome and expensive. Instead of borrowing from the medical model that uses broad-spectrum chemicals as "medicine" for the field, soil features like dark color, rich texture, and the size of compost are observed to prepare a disease-resistant environment. Such approaches are thought to be an indication of a healthy microbiome. In contrast, soil assays that combine field collection with laboratory identification of pathogenic and beneficial microorganisms are expensive and fail to reflect the full complexity of the microbiome. An attempt to understand soil species relative abundance would require laboratory cultures that change community structure. For example, using media or growth factors, researchers "grow out" invisible microbes collected from a field soil sample. The microbes then

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[28] The environmental toxicity of pesticide and herbicide manufacturing also stems from the making and shipping of component ingreedients. See: Bart Elmore, "Monsanto's Superfund Secret " *Dissent Magazine* April 1 2017; E.W. Lawless, R. Von Rumker, and T.L. Ferguson, *The Pollution Potential in Pesticide Manufacturing*, ed. Midwest Research Institute and United States. Environmental Protection Agency. Office of Water Programs. (Environmental Protection Agency, Office of Water Programs, Applied Technology Division, Rural Wastes Branch, 1972); P.R. Atkins, *The Pesticide Manufacturing Industry--Current Waste Treatment and Disposal Practices*, ed. United States. Environmental Protection Agency. and Office of Research Monitoring (U.S. Environmental Protection Agency, 1972).

[29] Monica Bruckner, "The Gulf of Mexico Dead Zone," https://serc.carleton.edu/microbelife/topics/deadzone/index.html.

reproduce to a great enough number for identification so that genetic or other screening assays can be used to detect the presence of key organisms. But as the laboratory growing conditions must be tailored to the species of interest, the results tell the researcher little if anything about the original ratio of the given species in the farm soil. This is a problem because it is the ratio of species in the microbial community that determines pathogen suppression, and competition dynamics within microbial communities limit a soil organism's niche. Some ecological models show direct suppression of disease by beneficial bacteria, but most suggest a more wholistic mechanism by which a diversity of organisms consume the resources needed for disease proliferation. However these models fail to capture the full complexity of a microbiome in which soil organisms can change their nutrient and energy sources, and the available "foods" and chemical signals that determine population size are partially determined by community structure. Thus the identifiers of healthy soil vary between sites, and it is difficult to test the full impacts of a soil amendment in the field.

Despite these obstacles to understanding the soil microbiome, researchers have identified the disease-fighting chemicals released by *B. napus*, though even this benefit to the soil may have had unintended promethean effects and exacerbated the problem of soil exhaustion when the crop was repeatedly planted or used for manuring at the industrial scale. In addition to any contributions of nitrogen from the crushed seed, modern researchers have shown that *B. napus* meal left from the oil press contains a high concentration of glucosinolates that break down into pest-killing isothiocyanate upon contact with water.[30] Potting and field trials of *B. napus* show

[30] Nikoletta Ntalli and Pierluigi Caboni, "A Review of Isothiocyanates Biofumigation Activity on Plant Parasitic Nematodes," Phytochemistry Reviews 16, no. 5 (2017); M. F. Cohen, H. Yamasaki, and M. Mazzola, "Brassica Napus Seed Meal Soil Amendment Modifies Microbial Community Structure, Nitric Oxide Production and Incidence of Rhizoctonia Root Rot," (2005); Mark Mazzola, Shashika S. Hewavitharana, and Sarah L. Strauss, "Brassica Seed Meal Soil Amendments Transform the Rhizosphere Microbiome and Improve Apple Production through Resistance to Pathogen Reinfestation," (2015); Clarissa Potgieter, Misha De Beer, and Sarina Claassens, "The Effect of Canola (Brassica Napus) as a Biofumigant on Soil Microbial Communities and Plant Vitality: A Pot

the suppression of oomycete molds like *Phytophthor*a, fungal root rots like *Rhizoctonia solani*, and the wireworm larvae of click beetles (*Coleoptera: Elateridae*). *B. napus* also appears to stimulate the growth of beneficial *Streptomyces bacteria and may trigger plant innate immune defenses against soil diseases.* But many questions remain unanswered. Some pest populations increase after application even when other targeted pests are better suppressed, and the repeated release of a potent chemical from a seed meal raises questions about poorly understood allelopathic impacts.[31] In fact, the chemical relationships between plants and manures are still poorly understood, and it may be that *B. napus* manures eventually saturate the soil with chemicals that signal immune reactions in plants or community microbial responses.

The historical record may shed new light on these questions. Indeed, oilseeds were considered exhausting and impoverishing in works published as early as the mid-seventeenth century, if not earlier. Though the term "exhaustion" does not map to modern scientific understandings, it is clear that manuring was not the cure and that problems of exhaustion cannot be explained by simple nutrient depletion. According to *De re Rustica*, "Rape and hemp are oil-

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Study," (2013); M. Mazzola et al., "Mechanism of Action and Efficacy of Seed Meal-Induced Pathogen Suppression Differ in a Brassicaceae Species and Time-Dependent Manner," *Phytopathology*, 97 (2007).

[31] William E. Parker and Julia J. Howard, "The Biology and Management of Wireworms (Agriotes Spp.) on Potato with Particular Reference to the U.K," *Agricultural & Forest Entomology* 3, no. 2 (2001); Mazzola, Hewavitharana, and Strauss, "Brassica Seed Meal Soil Amendments Transform the Rhizosphere Microbiome and Improve Apple Production through Resistance to Pathogen Reinfestation," Ecology and Epidemiology, 105 (215). D. M. N. Weerakoon et al., "Long-Term Suppression of Pythium Abappressorium Induced by Brassica Juncea Seed Meal Amendment Is Biologically Mediated," *Soil Biology and Biochemistry*, 51 (2012); M. Mark, M. F. Cohen, and U. A. Tree, "Suppression of Rhizoctonia Root Rot by Streptomyces in Brassica Seed Meal-Amended Soil," *Phytopathology*, 95 (2005); L. R. Elberson et al., "Toxicity of Rapeseed Meal-Amended Soil to Wireworms, Limonius Californicus (Coleoptera: Elateridae)," *Journal of Agricultural and Urban Entomology* 13, no. 4 (1996); Ric Bessin, "Wireworms," https://entomology.ca.uky.edu/files/efpdf1/ef120.pdf; Fanny Barsics, Eric Haubruge, and François Verheggen, "Wireworms' Management: An Overview of the Existing Methods, with Particular Regards to Agriotes Spp. (Coleoptera: Elateridae), *Insects*, 4, (2013); M. Mazzola et al., "Suppression of Specific Apple Root Pathogens by Brassica Napus Seed Meal Amendment Regardless of Glucosinolate Content," *Phytopathology*, 81 (2001); C. L. Reardon, S. L. Strauss, and M. Mazzola, "Changes in Available Nitrogen and Nematode Abundance in Response to Brassica Seed Meal Amendment of Orchard Soil," Soil Biology and Biochemistry, 57 (2013); M. F. Cohen and M. Mazzola, "Resident Bacteria, Nitric Oxide Emission and Particle Size Modulate the Effect of Brassica Napus Seed Meal on Disease Incited by Rhizoctonia Solani and Pythium Spp," Soil Biology and Biochemistry, 37 (2006).

bearing plants, and consequently impoverishers of the soil; but the former less so than the latter, owing to the greater succulency of its leaf."[32] Plants were thought to take less from the soil during the time when the leaves were succulent, and rape was thought to have a longer period of succulency before the seed began to form. Though rape was recommended as a better crop for thin soils than turnips by William Stevenson, he makes a point to note the crops potential harms to the soil in *General View of the Agriculture of the County of Dorset*. "Notwithstanding high encomiums which many pass on the nutritious qualities of rape, there are many who believe it to exhaust the soil…," he writes.[33] When describing practices in Suffolk in 1813, Arthur Young agreed that rapeseed was certainly an exhausting crop, though its planting would give rise to a good crop of wheat.[34]

Rape was not the only crop thought to exhaust the soils, and most authors attributed the problem to poor management instead of the crop. William Gooch in Cambridge recommended coleseed to prepare soils for wheat, but warned that hemp was too exhausting a crop.[35] Gooch also warned that oats became exhausting for the soils when grown in three consecutive plantings.[36] In 1813 John Middleton wrote that in Middlesex tenants burned land to "yield its treasures very freely," but then exhausted the land with successive corn crops. This gave tenants with short leases the power to exhaust soils.[37] However Middleton believed that coleseed

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[32] *De Re Rustica; or, the Repository for Select Papers on Agriculture, Arts, and Manufactures*, (London: printed for R. Davis, and L. Davis, 1769), p. 3-4.
[33] William Stevenson, *General View of the Agriculture of the County of Dorset: With Observations on the Means of Its Improvement* (G. and W. Nicol, 1812), p. 259.
[34] Arthur Young, *General View of the Agriculture of the County of Suffolk: Drawn up for the Consideration of the Board of Agriculture and Internal Improvement*, ed. Board of Agriculture (Sherwood, Neely, and Jones, 1813), p. 95.
[35] William Gooch, *General View of the Agriculture of the County of Cambridge* (Sherwood, Neely, and Jones, 1811), p. 116.
[36] Ibid., p. 117.
[37] John Middleton, *General View of the Agriculture of Middlesex : With Observations on the Means of Its Improvement, and Several Essays on Agriculture in General. Drawn up for the Consideration of the Board of Agriculture and Internal Improvement*, ed. Agriculture Board of and John land surveyor Middleton, 2nd ed. ed. (London : sold by G. and W. Nicol: Printed for Sherwood, Neely, and Jones, 1813), p. 372.

supported the best livestock and that it was bad husbandry that exhausted the soil as a succession of tares, turnips, clover, and cole fodders would rapidly advance the land into the productive class.[38] By the end of the eighteenth century such problems inspired a trend towards longer leases for crop fields so that tenants could invest more energy in preparing the soils. For example, in Somerset leases were extended to fourteen or twenty-one years but sometimes prohibited rape plantings. Rape, hemp, and flax were only considered great exhausters when they were grown for cash crop instead of for fodder, or some combination of fodder and seed, as this did not generate animal manure in the field.[39] Thomas Davis warned that in Wiltshire rapeseed exhausted the land only if it was allowed to take too deep a root, but was otherwise a nutritive milky food for ewes that have lambs.[40] Others denied that rape exhausted soils. "The idea that rape impoverishes the soil seems be a mistaken one, for in Essex they get good of wheat after it," wrote James Adams.[41]

Many of the designs forwarded by improvers helped mitigate such problems by limiting *B. napus* planting and manuring to small-scale rotations. When *B. napus* was used to convert marsh or more to pasture, it was often because the soil was too poor for turnips. In this case, *B. napus* served to introduce sheep to the land, and after the manure contributions improved soils, different fodders like clover and turnips were preferred. As *B. napus* was often selected for soils that were rank, moldy, or suffering from wireworm infestation, plantings functioned as a soil treatment rather than as a staple of industry. As a winter feed and green fallow, rape was often

[38] Ibid., p. 650.
[39] John Billingsley, *General View of the Agriculture of the County of Somerset: With Observations on the Means of Its Improvement*, ed. Board of Agriculture (Cruttwell, R. , 1798), p. 270.
[40] Ibid., p. 50.
[41] James Adam, *Practical Essays on Agriculture : Containing an Account of Soils, and the Manner of Correcting Them. An Account of the Culture of All Field Plants. Also, an Account of the Culture and Management of Grass-Lands; Together with Observations on Enclosures, Fences, Farms, and Farmhouses, &C. Carefully Collected and Digested from the Most Eminent Authors, with Experimental Remarks*, vii vols., vol. i (United States, North America: London : Printed for T. Cadell, 1789), p. 509.

planted during seasons when other crops might not flourish. But even so, rapeseed was rarely planted on large plots when used for fodder or feed. Only enough was grown to support grazing or the drying of stalk for a small but growing herd. Finally, as a seed crop, *B. napus* was often preceded by legumes, marling—or the addition of minerals like lime to the soil, and manuring in order to increase soil fecundity. These integrated designs maximized the potent benefits of the crop while mitigating the potential problem of soil exhaustion.

Of course not all period farmers implemented integrative designs. In fact, *B. napus* was also a frequent choice for the Tullians, and it was recommended by Tull himself as a more profitable option than any cereal. In the preface to the second edition of *Horse Hoeing Husbandry* published in 1733, Tull wrote "…I have been told by one who has been long a dealer on rape that he has made it larger and stronger in poor land by horse-hoeing than he could ever make it in the richest land by the common method."[42] Tullians worked to expand field size, plant successive crops of monoculture without rotation, and intensify agriculture through the reduction or omission of fallows.[43] In comparison to successive plantings of wheat, the use of *B. napus* in a Tullian design would have been particularly damaging over the long term for the problem of soil exhaustion. This demonstrates the need for more research on the unintended environmental repercussions of agricultural innovation during the eighteenth century.

The story of *B. napus* sheds new light on this question by serving an indicator of a wide range of improvement mechanisms and their incorporation into a cohesive, site-specific, plan for raising crops.   Because *B. napus* was used in such a diverse range of local and industrial-scale

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[42] Jethro Tull, *Horse Hoeing Husbandry, Fifth Edition* (Coastalfields Press, 2010), p. lvi. I. T., *The Horse-Hoing Husbandry: Or, an Essay on the Principles of Tillage and Vegetation. Wherein Is Shewn a Method of Introducing a Sort of Vine-Yard Culture into the Corn-Fields ... By I. T[Ull]* (1733), p. v.

[43] Wicker, "Note on Jethro Tull Innovator or Crank?," p. 47; Sayre, "The Pre-History of Soil Science: Jethro Tull, the Invention of the Seed Drill, and the Foundations of Modern Agriculture," p. 855-57.

improvements, it serves as an ideal case study of design diversification and the deep marriage between land and industrial production in the eighteenth century. Future chapters will focus more narrowly on the importance of *B. napus* in the Norfolk, convertible husbandry, and the plant manure revolution, which all combined to increase soil fecundity as well as productivity during the long eighteenth century.   But this chapter more broadly confirms that *B. napus* was considered as a form of improvement by period farmers. From this study we trace *B. napus* to the mid-seventeenth century through its references in the English improvement literature. As the crop was studied by botanists and categorized according to Linnaean taxonomies, we also see descriptions of *B. napus* in period improvement publications.[44] From the social study of the authors who integrated *B. napus* into agronomic designs, we learn that plantings were linked to yield increases on poor soils. We also see a wide disbursal of *B. napus* for improvement through every county in England and most of the counties of Scotland.

Finally, the chapter concludes by tracing *B. napus* through the oil crushing production pipeline to explore the integrated aspects of industrial designs. Harold W. Brace sites more than 640 seed crushing mills in the nineteenth century, and he believes that many served to primarily crush *Brassica napus* into oil.[45] At the beginning of each of these production chains stood fields of yellow flowers dotted with windmills and sheep. At the end of the production chain, the brown flakey meals or cake left from the oil press were sold as a manure or mixed with animal feed. Thanks to rapeseed oil, many country villages enjoyed higher grain yields and some even saw street lighting from local oil by the early eighteenth century despite their small

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[44] Carl von Linné, *Species Plantarum : Exhibentes Plantas Rite Cognitas Ad Genera Relatas, Cum Diferentiis Specificis, Nominibus Trivialibus, Synonymis Selectis, Locis Natalibus, Secundum Systema Sexuale Digestas*, vol. 2 (1753) (Berlin : Junk, 1753), p. 666.
[45] W. Brace, History of Seed Crushing in Great Britain, 1960, p. 99-158.

populations.[46] In contrast, many larger cities would wait until the 1760s for oil lamps. Rape mills also fed soap making industries and offset England's dependency on imported Mediterranean olive oil for textile finishing. As the improver James Hutton wrote "Britain does not possess a climate capable of producing the olive; and it is chiefly from our pastures that we form our oily matter…"[47] The improvers integrated the rotations and fallows that ensured soil health for on-going production into the industrial production of oil through small-scale, localized supply chains that recycled *B. napus* meals back into the fields as manures. This offers a sharp contrast to the olive oil shipped from the Mediterranean, the whale oil harvested from the sea, and the animal lards which often required long-distance transport when produced at the scale needed for spinning and textile making. Thus, the story of *B. napus* in the eighteenth century British agricultural sector allows us to reconstruct a local production system that demonstrates the integration of local agriculture, local milling, and local byproduct recycling.

II. From Improvement to Widespread Dispersal

It is difficult to define a term like "improvement" that encompasses a wide range of economic development activities ranging from the establishment of farms for orphans to the building of factory systems that replaced low input and output systems with enclosed farms that supplied new local mills.[48] Improvement publications covered everything from the killing of rats to the most fuel-efficient use of fire for industry. They reviewed cheese making and the best uses of pig grease to prevent iron from rusting. The 1733 *Chiltern and Vale Farming Explained*

[46] Joan Thirsk, *Alternative Agriculture: A History From the Black Death to the Present Day*, 1997, p. 78.
[47] James Hutton, "Manuscript of 'Elements of Agriculture'," (Unpublished: National Library of Scotland 1794), p. 532, 979.
[48] T. C. Smout, "A New Look at the Scottish Improvers," *The Scottish Historical Review* 91, no. 231 (2012), p. 131-33.

describes the use of hogs hair and rape oil cakes for manuring.[49] Improvement designs also integrated agricultural best practices into coal-powered factory development. The unpublished 1770 *Essay Towards the Improvement of Lands in the East Riding of the County of York* makes hardly a mention of crops or planting practices. Instead J. Midgeley focuses on the development of coal technology for broad cloth so that wool would no longer would be sent by water carriage to other counties for washing, combing, spinning, and weaving.[50] The term improvement carried many different historical meanings because designs integrated growing practices with industry. In the organic economy before industrialization, land still played a dominant role as the source of fuel and raw materials for industry, and growth in field-based markets ran the risk of limited future returns due to soil depletion and exhaustion.[51] It should not come as a surprise then that publications on improvement focused on best practices for tilling, marling, and planting. Yet despite the complexities and contradictions of the capitalist and industrial goals of improvers, the integrative nature of their designs highlights genuine desires to bring education, higher quality buildings and infrastructure, and jobs to poor rural communities charged with food production for a growing industrial sector.[52]

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[49] William Ellis, *Chiltern and Vale Farming Explained : According to the Latest Improvements*, ed. William ca Ellis (London: Printed for the author William Ellis of Little-Gaddesden near Hemstead in Hertfordshire. And sold by W. Meadows ... H. Walthoe ... J. Parker ... 1733), p. 398-9.

[50] J. Midgeley, "Essay Towards the Improvement of Lands in the East Riding," in *Papers of the Hotham Family of Scorborough and South Dalton*, ed. Hull History Centre (1770).

[51] The model of the eighteenth century organic economy proposed by Tony Wrigley pits the fields against the forests so that land clearing and soil exhaustion from growth in grain and livestock markets limits the future rate of growth in wood-product markets. Organic markets were also intra-regulating because the rate of resource renewal and soil regeneration determined long-term growth rates. E. A. Wrigley, *Continuity, Chance and Change : The Character of the Industrial Revolution in England* (Cambridge England ; New York: Cambridge University Press, 1988).

[52] T. M. Devine, *Clearance and Improvement : Land, Power and People in Scotland, 1700-1900* (Edinburgh: John Donald, 2006). *The Transformation of Rural Scotland : Social Change and the Agrarian Economy, 1660-1815* (Edinburgh: Edinburgh University Press, 1994). Fredrik Albritton Jonsson, *Enlightenment's Frontier : The Scottish Highlands and the Origins of Environmentalism*, in Lewis Walpole series in Eighteenth-Century Culture and History (New Haven, Connecticut: Yale University Press, 2013). Paul Slack, *The Invention of Improvement : Information and Material Progress in Seventeenth-Century England*, First edition. ed. (Oxford: Oxford University Press, 2015).

In this section we will focus more narrowly on the planting designs that contemporaries imagined might help boost local industry. Improvers described the multiple agricultural practices integrated into a single field, and as the eighteenth century progressed, these designs became more complex. Best practices covered the number of tilling and harrowing cycles, the type and seasonal timing of marling and manuring, the rates of seeding and manuring per acre, the use of horse-hoes or seed broadcasters, the possible crop rotations, and when to introduce marling and manuring to a rotation. As Thomas Christopher Smout described, the improvers believed that the bettering of the people through agriculture would go alongside with the improvement of the economy.[53]

Smout argues that interest in agricultural progress was particularly strong in early modern Scotland. He traces the origins of improvement in Scotland to 1681 when "the Duke of York called together mercantile experts to consider why Scotland did not enjoy the level of wealth of her neighbors."[54] Scottish growers were largely excluded from the agricultural correspondence initiated by the Royal Society of London in the mid-seventeenth century, and they made no similar effort to launch a domestic study of growing practices. Thus, though both kingdoms enjoyed botanical gardens and estate agricultural projects during the Renaissance, England led the way in agricultural improvement in the seventeenth century. Scotland underwent an agricultural revolution during the mid to late eighteenth century when learned societies became popular during the Scottish Enlightenment and influenced the founding of agricultural improvement groups that began to debate and test best growing and tillage practices.[55] By the late eighteenth century, Scottish writers like University of Edinburgh faculty William Cullen,

[53] Smout, "A New Look at the Scottish Improvers," p. 132.
[54] Ibid., p. 126.
[55] Ibid., p. 126-8.

parliamentarian John Sinclair, who founded the Board of Agriculture, and Adam Dickson, minister of the Church of Scotland, were influencing the future of agricultural production and rural economic development for Britain.

To trace the arc of integrative design, we must leave eighteenth century Scotland and move backwards in time one centiury to the Royal Society of London. *B. napus* appears in some of the earliest works published by English improvers. In 1664 the Royal Society of London set up a Georgical Committee to investigate agriculture, and questions were sent to farmers in many counties in England.[56] Rape makes at least one appearance in these early correspondences held at the Royal Society Archive in a volume of agricultural writings. Bound among an Account of Normandy cider, directions for cultivating vines, and the details of grain preservation, we find the 1664 *Answers to the queries concerning agriculture from Home Beakon, Darwent and Holdenshire*. An anonymous Yorkshire farmer portrays rapeseed as elemental in his response. Together with fire, blood, and earth, rape helped protect and nurture the soil. The anonymous farmer writes:

> …with wheat when we sow it, which preserves it from vermin and from being lain…. We likewise sow rape or coleseed, sometimes upon fallow, ordered only as for corn, only made much fatter, but lying it very dry and beginning to plough for burning soon after May Day and sows at or soon after midsummer, the ashes being spread and ploughed once again, which we so let lie and never harrowed at all. We choose the brightest coloured seed and sows about a peck upon a statute acre.[57]

The images of ashen fields tended with blood meal and bright seed represent primary trends in early modern agriculture. From the end of Elizabeth's reign to the beginning of the Agricultural Revolution, farm systems became more integrated—before the Rotherham swing plow, and the

[56] Koen Stapelbroek and Jani Marjanen, *The Rise of Economic Societies in the Eighteenth Century : Patriotic Reform in Europe and North America* (Houndmills, Basingstoke, Hampshire: Palgrave Macmillan, 2012), p. 127.
[57] "Classified Papers, Concerning 'Agriculture'," in *Classified papers of the Royal Society*, ed. Royal Society (Royal Society Archives, 1660-1741), Document 23, p. 2.

Norfolk Rotation became prevalent in the mid-to-late seventeenth and early eighteenth centuries, the less effective but still beneficial practice of seed sorting was widely adopted in the late sixteenth century. Farmers selected the best seed to reproduce the crop based on qualitative characteristics like size, color, and transparency. Around this same time, blood meal and manure were integrated into three field series plantings as fertilizers, and fallow cycles became more strategically managed to prepare the soil for nutrient demanding cash crops.[58]

Here our farmer confirms rapeseed's most common use—it was "ordered only as for corn," which means that it was planted in series. In contrast, other plants like turnips might have been used to prepare the land for wheat or perhaps clover for oats, although the series recommendations varied from farmer to farmer. These chronologies of plantings matured into the rotation cycles of the eighteenth century, when the Norfolk treatment alternated turnips, barley, and clover before wheat.[59]

In the seventeenth century rapeseed was also coupled with another form of improvement—the draining of marshlands and swamps to expand arable acreage. This is why rapeseed was frequently grown in the Fenlands, where large spans of marsh were converted to farmland in the early seventeenth century.[60] Indeed, in the *English Improver Improved*, Walter Blith lists rapeseed as "another excellent good meanes for the improving of land." Blith recommends using rapeseed or coleseed in marshland or recovered sea, or "any lands, very rank and fat, whether arable or pasture."[61] According to Blith, the "turnip seed" was grown among rape, and both were harvested for oil.

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[58]Eric Kerridge, *The Agricultural Revolution* (New York: A.M. Kelley, 1968), p. 15-40.
[59] Mark Overton, "The Diffusion of Agricultural Innovations in Early Modern England: Turnips and Clover in Norfolk and Suffolk, 1580-1740," *Transactions of the Institute of British Geographers* 10, no. 2 (1985), p. 212-14.
[60] Joan Thirsk, *Alternative Agriculture: A History from the Black Death to the Present Day* (Oxford: New York : Oxford University Press, 1997), p. 76-7.
[61] Walter Blith, *The English Improver Improved; or, the Survey of Husbandry Surveyed Discovering the Improveableness of All Lands*, ed. Walter fl Blith, The third impression much augmented, with an additionall

Because few crops flourished in sandy, soggy grounds, rapeseed helped make it possible to convert marshes to farmland. By planting rape, animals could begin to graze and gradually improve soils through their manure. In 1652 Samuel Hartlib published a letter that he received regarding the defects and remedies of English husbandry. The author mentioned the importance of rapeseed:

> ….so that improvement is very considerable: the same I may say of Fens, especially that great Fen of Lincolnshire, Cambridge, Huntingdon consisting as I am informed of 380,000 acres, which is now almost recovered; and a friend of mine told me very lately that he had proffered a mark per acre: for 900 Acre together, to sow rape on… for improving a Kingdom is better than the conquering of a new one.[62]

Rapeseed made it possible to earn a profit from land that could support few other commodities. This example is particularly helpful for illustrating the integrative nature of British agricultural designs during the eighteenth century. It is humorous that one motto of the integrative design movement is to 'grow it local' and buy from 'local growers.' Yet here an analogous mantra relates the question of local agriculture to trade dependency on colonial lands. According to the author, sowing rape for improvement was a better option than conquering a new kingdom in order to secure additional resources. Rapeseed is similarly noted in *An Act for Drayning the Great Level of the Fens*. Here the opportunity to plant rape was considered a primary advantage that justified the costs of wetland drainage. This is because rape advanced the trade of clothing and spinning of wool and could be used to make soap.[63]

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discovery of the severall tooles and instruments in their forms and figures promised, with a second part containing six newer peeces of improvement ... ed. (London: Printed for John Wright, 1653), p. 253.

[62] *Compleat Husband-Man : Or, a Discourse of the Whole Art of Husbandry; Both Forraign and Domestick. : Wherein Many Rare and Most Hidden Secrets, and Experiments Are Laid Open to the View of All, for the Enriching of These Nations. Unto Which Is Added a Part*, ed. Samuel Hartlib (Place of publication not identified: Printed and are to be sold by Edward Brewster at the Crane in Paul's Church-yard, 1659), p. 41.

[63] "May 1649: An Act for Drayning the Great Level of the Fens, Extending Itself into the Counties of Northampton, Norfolk, Suffolk, Lincoln, Cambridge and Huntingdon, and the Isle of Ely, or Some of Them.," in Acts and Ordinances of the Interregnum, 1642-1660. Originally published by His Majesty's Stationery Office, London, 1911., ed. British History Online (1649).

While such agricultural projects were more popular in England than in Scotland during the seventeenth century, this changed during the eighteenth century when many small improving societies dedicated to agricultural education and field tests began to emerge.[64] Smout dates the beginning of the Scottish improving movement "and its crusade against ignorance" to 1723 with the foundation of the Edinburgh-based Honorable the Society of Improvers in the Knowledge of the Agriculture in Scotland.[65] This was the first proper agricultural society in Europe dedicated to spreading the 'best practices' of agriculture, including the horse-hoeing husbandry of Jethro Tull, "whom their secretary regarded with sensible caution," according to Smout.[66] Other groups followed, including the first state-financed group, the Trustees for Improving Manufacturers in 1727.[67] In the *1735 Articles Establishing a Company for Improvement by Agriculture*.[68] The *Articles* established funds to lease farms in the respective divisions of Perthshire for improvement projects, and listed terms for shares of stock, profit, and the election of directors. The Edinburgh Society for Encouraging Arts, Sciences, Manufactures and Agriculture was founded in 1755, and the Highland and Agricultural Society was set up in 1784.[69]

From these and many other Scottish improving groups came numerous publications on agriculture. Adam Dickson was the first clergyman recruited to the Honourable the Society of Improvers, and in his 1762 *Treatise of Agriculture*, he recommends introducing rapeseed by calling it by the common name "coleseed" for sheep or cattle as a mechanism for introducing greens to the land.[70] Though Dickson did not advise coleseed for feeding dairy cows due to the

[64] Smout, "A New Look at the Scottish Improvers," p. 126.
[65] Ibid., p. 130.
[66] Ibid., p. 131.
[67] Ibid., p. 132.
[68] "Articles Establishing a Company for Improvement by Agriculture," ed. Atholl Estates (Blair Castle Archive, 1735).
[69] Smout, "A New Look at the Scottish Improvers."
[70] A. Dickson, *A Treatise of Agriculture. A New Edition* (A. Kincaid and J. Bell, 1770), p. 310, 95; Smout, "A New Look at the Scottish Improvers," p. 134-5.

flavor of the butter, he does consider the crop to be improving. Dickson worked to increase the efficiency of *B. napus* manuring and planting with the use of the seed drill and horse-hoeing, and in doing so he avoided the problems of Tull's methods which prevented foddering. According to Smout, Dickson "did not hesitate to criticize Jethro Tull for saying that horse-hoeing could take the place of manuring."[71] William Cullen was a member of the Edinburgh Philosophical Society and gave nine lectures on the chemical and physical means of improving fertility in 1768.[72] In his hand- written expository on the best management of cattle, "Lint seed and rape seed oil cakes are found extremely beneficial for fattening."[73] Rapeseed cakes were even recommended above traditional feeds for the phase when livestock were fattened for market. In Cullen's work every aspect of the cow, from the amount of skin fat to the breadth of the shoulders, depended on the timing and practices of feeding. Having feed or fodder, in turn, required improved planting and manuring practices.

Scotsman James Hutton is best known for his contributions to geology, but he was also an eminent agricultural theorist, elected to the Société Royale d'Agriculture de Paris for his work as an improver. He recorded his series of agricultural projects conducted on a lowland farm in Berwickshire in an unpublished, unfinished manuscript *The Elements of Agriculture*, at the time of his death. Hutton remarks that "In Norfolk the coleseed is sown upon a summer fallow, and stands for seed next summer."[74] Here a single planting of *B. napus* was integrated into two cycles of production—fallow cropping, which sometimes served as fodder, and seed production

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[71] "A New Look at the Scottish Improvers," p. 135.
[72] The Edinburgh Philosophical eventually became the Society Royal Society of Edinburgh, which also served medical, historical, and other learned communities. Its membership published numerous works on agriculture that eventually gave rise to an offshoot group called the Wernerian Natural History Society, which focused on plants.
[73] William Cullen, "Fragments by William Cullen on Agriculture," ed. University of Glasgow (Archives and Special Collections, Manuscripts, 17—), p. 8.
[74] Hutton, "Manuscript of 'Elements of Agriculture'," p. 533, 980. Smout, "A New Look at the Scottish Improvers," p. 138.

for oil crushing. Sometimes a grass or turnip crop was even planted between the two temporal shootings of rape.

Towards the end of the century, designs more frequently integrated the crushed *B. napus* cake from the oil press as a manure for turnips. Such designs were suggested by James Anderson, also a member of the Edinburgh Philosophical Society, who published the 1797 *Essays Relating to Agriculture and Rural Affairs* and founded *The Bee*, a forerunner to the popular *Farmers Magazine* started in 1800.   There are numerous references to rapeseed and rape dust in *Farmers Magazine*. For example, in an 1805 letter on *Turnip Husbandry*, rape dust is applied to the land "by sowing it by hand from a sheet, just before forming the drills upon which the turnip seed is to be sown…. The short continuance of the fertilizing quality of rape dust is no objection in the turnip husbandry."[75]

Some of the improvement societies also sponsored their own internal publications. The Highland and Agriculture Society published *Transactions*, which contains numerous references to rape dust manuring. For example, in 1824 a field trial by Mr. Boswell was published that compares one-half acre of planted turnips manured with a ton of rape-cake to one-half acre manured with cake and four tons of stable dung.[76] The cake was mixed with seven cart loads of earth and spread in drills. The site manured with stable dung and rape cake produced about half a ton greater yields for a total of about 32 tons of turnips between the two plots.[77]

The most prolific collection of improvement writings also originated in Scotland. The *General Views* were the first attempt made in any country to survey the details of agricultural improvement at the spatial resolution of county and with the use of a standardized format of

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[75] "On Turnip Husbandry," *The Farmer's Magazine*, no. v. 6 (1805), p. 268.
[76] Highland and Agricultural Society of Scotland, "Experiments to Ascertain the Comparative Value of Different Manures in Raising Turnips " *Transactions of the Highland and Agricultural Society of Scotland* 1 (1829), p. 73.
[77] Ibid., p. 73.

subject headings.[78] Published between 1793 and 1817, these agricultural surveys facilitated comparisons between the crops, rotations, tillage and harrowing practices, and other improvements in England, Wales, Scotland, and Ireland.[79] The project was launched by John Sinclair of the family of the Earls of Caithness. Sinclair became an influential politician and improver and launched the Board of Agriculture in 1793 with the support of government grants and subscriptions.[80] Though the board was founded by Royal Charter, it functioned as a voluntary society with private minutes and never became a government department.

The *General Views* were one of many collections published and promoted by the Board of Agriculture, but unlike the *Code of Agriculture*, the *General Report of Scotland*, and the *Statistical Account of Scotland,* the *General Views* covered the widest geographic span with the greatest attention to the details of agricultural improvement. According to Heather Holmes, even Sinclair doubted that such a survey was possible in Great Britain in any reasonable space of time.[81] Sinclair described the *General Views* as the "the greatest undertaking ever attempted by an institution," writes Holmes.[82] Such a process was laborious during an age when books were handwritten and printing presses were only beginning to use hand presses with iron frames.

By tracing *B. napus* through the *General Views*, we uncover the evolving parameters of period integrated designs. In 1794 Thomas Wedge wrote in the *General View of the Agriculture of the Palatine of Chester* that it was to the benefit of the skillful husbandman "…and not less to the improvement of the soil, to have a crop of turnips, or where the land is not for turnips, of

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[78] Heather Holmes, "Sir John Sinclair, the County Agricultural Surveys, and the Collection and Dissemination of Knowledge 1793–1817, with a Bibliography of the Surveys: Part 1.," *Journal of the Edinburgh Bibliographical Society* 7 (2012): p. 28-9, 36.
[79] Ibid., p. 28-9 36.
[80] Ibid., p. 37, 43.
[81] Ibid., p. 29-30.
[82] Ibid.

rape, coleseed, sec."[83] Modern food security relies upon the wide diversity of crops available in the agronomic system as this protects against seed failure. But the integration of new fodders was a slow process that evolved over time because it required the introduction of more than one new plant. As the 1794 writings of John Bailey and George Culley in Cumberland demonstrate, new fodders were also strategically combined with food crops in rotation. Bailey and Culley criticized farmers for growing nine or ten crops of cereal successively and damaging the prospect of a good future yield. Instead they recommend a design that included rapeseed as part of a robust integrated system in which many improvements functioned as part of a temporal plan. They write:

> Had these lands been continued in tillage only three years at one time; the first year oats; second, fallow, turnips, or rape; the third, wheat or oats, or (if the soil suited) barley sown up with clover and ray grass, and depastured with sheep for three, four, or five years, according to circumstances and situations, we will venture to say, the land would have gone on improving, from rotation to rotation; would have been more profitable, and put on a very different aspect to what it does at present, and been worth double to what it now lets for.[84]

Here we see that rape was one of several improvement technologies used for fallowing and course design. The integration of manure from grazing, green fallowing, and the use of alternative crops renewed soils for cereals and increased the value of the land.

Such examples are abundant in publications from a wide range of geographies. In the first edition of the *General Views of the Agriculture of the County of Bedford*, Thomas Stone recommended drainage to cultivate wheat, beans, and artificial grasses "…thus promoting more abundantly the means of improving and supporting cattle and sheep." He notes that on such land

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[83] Thomas Wedge, *General View of the Agriculture of the County of Palatine of Chester: With Observations on the Means of Its Improvement* (C. MacRae, 1794), p. 53.
[84] Ibid., p. 33.

"green winter food may be produced as cole, rape, or cabbages…".[85] The second edition of the work was written by Thomas Batchelor, who said that "the plants which are said to ameliorate or improve the soil" all struck their roots deep into the ground below the plough line. On the list of these "tap rooted vegetables" he lists coleseed, cabbages, and turnips.[86] In 1811 William Gooch similarly wrote in the *General View* published for the Cambridge that cole seed improved the land "in a superlative degree," and provided "a much greater supply of mutton and meat at the season of the year when it is most wanted…".[87] According to Gooch, "when the cole seed has been eaten on the ground especially after a fallow, the fine fen moory soil is in a most rich fertile state and never fails to produce a prodigious crop of grain that is sown upon it."[88] These examples not only show that *B. napus* was considered an improving crop by period authors, but that it was integrated into the systems used to produce livestock, increase herds, and manage manure contributions to arable acres.

We next turn to the question of geographic distribution. Rare Church of England tithe surveys located at Lambeth Palace confirm the frequent plantings of rapeseed along with other improvement crops. Conducted in the first years of the nineteenth century in Kent, the surveys list all tithed crops on a site. Because surveys are not available for many counties or many years, and only Church holdings were surveyed, we can say little about the number of farms that grew any given crop in the region. However, because the tithe surveys list planting in terms of acres, roods, and perches, we can compare the frequency of rape plantings within a farm to those same

[85] Thomas Stone, *General View of the Agriculture of the County of Bedford: With Observations on the Means of Improvement*, ed. Agriculture Board of and Thomas d Stone (London: Printed by E. Hodson, Bell-Yard, Temple-Bar, 1794), p. 62-3.
[86] Thomas Batchelor, *General View of the Agriculture of the County of Bedford: Drawn up for the Consideration of the Board of Agriculture and Internal Improvement* (Sherwood, Neely and Jones, 1813), p. 354.
[87] Gooch, *General View of the Agriculture of the County of Cambridge*, p. 115.
[88] Ibid.

values for other crops. This is a remarkable opportunity, as the other archives commonly used for historical research are more limited.

For example, probate inventories conducted at the death of the farmer only list the crops planted and often exclude the acreage.[89] In the Imperial System there were four roods in an acre and 40 perches in a rood.[90] The earliest valuations in September of 1806 show rape on only seven of 291 acres and 2 roods at the Rectory of Oxney, and in October on five of 827 acres in Fingleson.[91] However other sites had far more rape or cole planted. The April 1810 survey and valuation for the Shepherdswell Parsonage in the County of Kent had 26 acres of coleseed.[92] This same year a farm in Challock had planted 60 acres of turnips and cole.[93] In contrast, the Rectory of East Sutton in Kent was growing 50 acres of fall coleseed in November of 1810. Turnips were planted in 80 acres, beans, peas and tares on 70 acres, and 250 acres of barley and oats surpassed 120 acres of wheat.[94] Notes from a survey conducted in Dover recommended "turnips and rape for sheep feed" and indicated that 130 acres of the mixed crops were planted on site in October 1831.[95] In Oxney in July 1834 there were 62 acres of turnips or rapeseed on only 317 total acres. On the small site wheat was planted on 46 acres, barley on 35 acres, and oats on 16 acres. Clover was planted on 17 acres, and tares and pasture were planted on the remaining lands.[96] While it is difficult to deduce patterns from such a small data set, we see rapeseed on both small and large farms, and it was likely planted in both the spring and fall.

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[89] Overton, "The Diffusion of Agricultural Innovations in Early Modern England: Turnips and Clover in Norfolk and Suffolk, 1580-1740."
[90] "Measurements ", https://www.nottingham.ac.uk/manuscriptsandspecialcollections/researchguidance/weightsandmeasures/measurements.aspx.
[91] "Tithe Surveys 32," ed. Lambeth Palace Library (Lambeth Palace). p. 55, 129.
[92] "Tithe Surveys 86," ed. Lambeth Palace Library (Lambeth Palace), p. 105.
[93] "Tithe Surveys 28," ed. Lambeth Palace Library (Lambeth Palace), p. 133.
[94] "Tithe Surveys 86," p. 164.
[95] Ibid., p. 86.
[96] "Tithe Surveys 32," p. 133.

Sometimes rape represents a sizeable number of planted acres on a farm. Though it is rare to find planting logs in tithe surveys, the presence of rapeseed offers additional qualitative proof that it was planted for improvement with a moderate frequency.

Similarly, by using data mining (R) and keyword searches for rape, cole, rapeseed, coleseed, oil, oilseed, napus, and Brassica, we can estimate the total number of counties growing *B. napus* were estimated from the *General Views*. Approximately 167 *General Views* were located in a digitized format for about 88 different counties in England, Wales, and Scotland. Rapeseed was found in nearly every survey as feed, green fallow, oilseed, or manure. In Scotland there only five counties for which no rape was found in the *General Views*—Angus, Elgin or Moray, Peebles, Renfrewshire, Tweedale, and West Lothian. In England the plant was noted in all surveys with the exception of those conducted in Westmoreland, Salop, and Oxfordshire. In five of the counties with reprinted second editions—Devon, Dorset, Huntingdon, Middlesex, and Worcester— rape was listed in the first but not the second printing.[97] Yet the absence of rapeseed from the *General View* should not be taken as an indication of the plants absence from the county at the time. If farmers had not reported the crop in the survey, or if those growing rapeseed were not surveyed, the *General Views* would include no record.

For example, we know that rapeseed was grown in Oxfordshire despite its omission from the *General Views* because court records archived at the Oxfordshire History Centre document the penalties for theft of the plant. Trial records from Oxfordshire illustrate that that the *General Views* are not entirely comprehensive. Mary Hickman of Wheatley was convicted on May 5, 1855 for stealing rape growing the prior month in the Parish of Holton. The rape plants were

[97] See Appendix 1 for the complete table.

valued at three pence and belonged to the enclosed property of Robert Parrot. Hickman was ordered to "forfeit and pay the sum of five shillings over and above the value of the articles so stolen."[98] About two weeks later in the Parish of Holton in Oxfordshire, John Wing was also convicted for stealing rape greens worth one shilling. The same Robert Parrott was the victim of this second theft. Wing was required to pay the sum of five shillings as a fine in addition to the one shilling for the stolen crops.[99] Both rulings relied upon a law that prohibited the stealing and carrying away of 'cultivated plants used for the food of beasts." Should either culprit have failed to pay, they would have faced "imprisonment in the House of Correction at Oxford there to be kept to hard labour for the space of fourteen days," according to the court reports.[100] These examples show that we cannot rely on the *General Views* alone to understand dispersal; we cannot say how many farms in a community planted the crop, how regularly it was grown, or the number of acres planted with rape. Yet at the very least the *General Views* confirm that *B. napus* was integrated into the local agricultural system in nearly every county in Great Britain.

The surveys are also reliable for incorporating a peer-review structure of sorts. Though historians have come to rely on the *General Views* for their spatial resolution and unprecedented details, many have overlooked the successive re-printing of the series. Sinclair asked surveyors to use both the original surveys and the manuscript comments as their basis for the second printing of revised surveys.[101] Yet the rare correspondence in the archives illustrates that Sinclair and his authors did more than assign reprints. In an October 20, 1794 letter held at the Beverley Treasure House, Sir John Sinclair requested that some of the Board of Agriculture

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[98] "Certificate of Conviction of Mary Hickman, Wheatley," ed. Oxfordshire History Centre (1855), p. 5.
[99] "Certificate of Conviction of John Wing, St Thomas, Oxford, Labourer," ed. Oxfordshire History Centre (1855), p. 1.
[100] "Certificate of Conviction of Mary Hickman, Wheatley." "Certificate of Conviction of John Wing, St Thomas, Oxford, Labourer."
[101] Holmes, "Sir John Sinclair, the County Agricultural Surveys, and the Collection and Dissemination of Knowledge 1793–1817, with a Bibliography of the Surveys: Part 1.," p. 38.

reprints should be sent around to Gentlemen resident in the country "with a view to the supplying of any deficiencies and the rectifying of any errors they might discover therein."[102] The accompanying reports were consolidated by an assignee. Though the formats were not well followed and served as only a reminder of the subjects to cover, there were attempts to debate and revise the subject headings and organization guides during the preparation of the second reprint.[103] The Board even sometimes took the opportunity to print a third edition, especially in the period between 1805 and 1808.[104]

The *General Views* were also unique for including the middling sort of tenant farmers and clergy as contributors to Britain's most famous improvement series. According to Smout, the authors included sixteen clergy, eight were farmers, seven were proprietors or military gentlemen, and two were factors.[105] In addition, there was a lawyer, surgeon, journalist, land surveyor, and six with unknown occupations. "Nothing could more clearly demonstrate how the rural middle class was coming to displace landowners in the public forum of agronomy," Smout notes.[106] The abundance of rapeseed in the *General Views* suggests that the technology was used widely by tenant farmers and middling sorts outside the gentry.

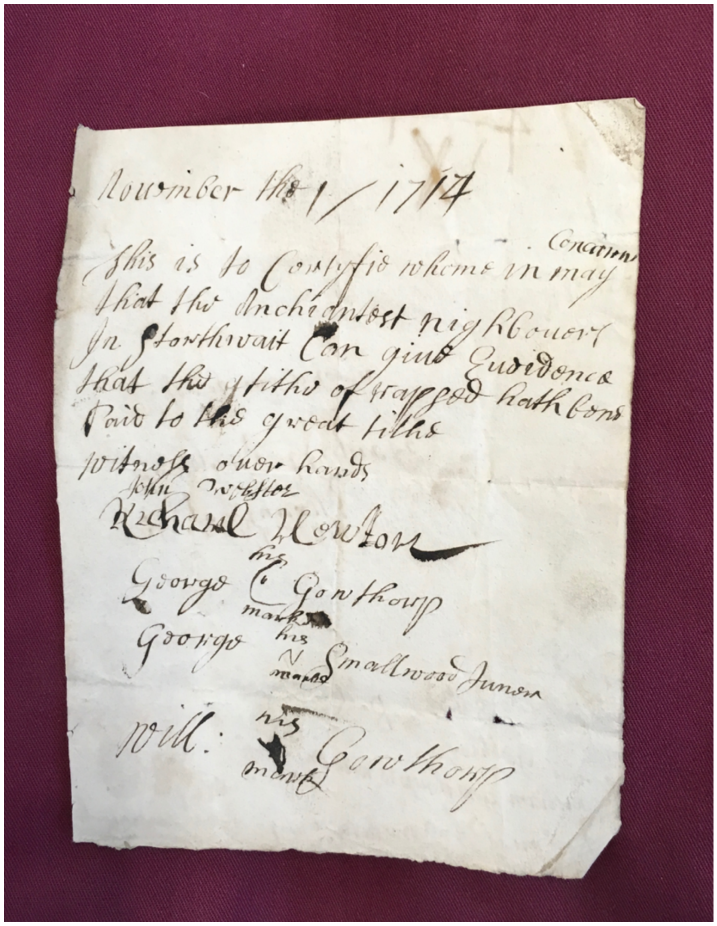
However there is actually evidence that rapeseed was planted by illiterate farmers generations before the *General Views* were published. For example, a November 17, 1714 letter from the East Riding of Yorkshire certifies and gives evidence that "the tithe of rape hath been paid to the great tithe."[107] As to the class of the farmers who owed payment, the letter is signed

[102] "Letter from William Wilberforce," ed. Beverley Treasure House (1794).
[103] Holmes, "Sir John Sinclair, the County Agricultural Surveys, and the Collection and Dissemination of Knowledge 1793–1817, with a Bibliography of the Surveys: Part 1.," p. 34, 35.
[104] "Sir John Sinclair, the County Agricultural Surveys, and the Collection and Dissemination of Knowledge 1793-1817, with a Bibliography of the Surveys: Part 2," *Journal of the Edinburgh Bibliographical Society* 8 (2013): p. 72.
[105] Smout, "A New Look at the Scottish Improvers," p. 141.
[106] Ibid.
[107] "Certificate Relating to Tithe of Rape Seed in Storthwaite," ed. Hull History Centre (Hull University Archives, Held at the Hull History Centre, 1714).

with symbols in place of the farmer's names, which suggests the signers George Gonthorp, Goerge Smallwood Junson, and Will Gonthorp lacked the literacy to read and write. Their full names were written by the clergyman who drafted the letter. Much later in the century, rapeseed appears in another tithe dispute in the parish of Aldborough in the East Riding of Yorkshire. In 1778 George Highman refused to pay one twelfth of the sum he earned selling a crop of rapeseed to the Vicar. Because his township was free of all tithes except those of wool, lamb, and poultry, Highman assumed that rapeseed was also exempt from tithes.[108] As one tithe payment had been made on a rape crop 14 or 15 years prior, the Vicar demanded payment. However the case was decided in favor of Highman on March 10, 1779. It was found that the Vicar had no right to the 12th part of money received for the crop as there was no sure precedent to demonstrate a custom of rape tithe. Rape had been too frequently planted in the area, and most farmers were not paying tithes on their crop. According to the notice, "The Vicar cannot recover any satisfaction from George Highman for the tithes of his last year's rape…"[109] Though these narratives offer only anecdotal evidence that rape was widely grown, they do confirm early plantings among an illiterate class of farmers and frequent plantings in at least one parish. This strongly suggests that rapeseed was more than an agronomic fashion or a publication trend.

Accounts of local harvest practices similarly confirm the importance of *B. napus* to the middling classes. During the growing season, the locals would gather together to help thresh and tie rape stock into sheaves. At the end of the day they would dance and drink. According to John Baily, who wrote about the custom in 1810:

[108] "Case and Opinion: Tithe on Crop of Rape at West Newton.," in *Chichester-Constable Family and Estate Records* ed. Beverly Treasure House (Beverly Treasure House, 1779).
[109] Ibid.



November the 1/ 1714

This is to Certyfie whome in may Concarn
that the Anchiantest nighbouers
In Storthwait Can give Euidence
that the tithe of rappseed hath bene
Paid to the great tithe

witness ouer hands
John Webster
Richard Newton
George his mark Gowthorp
George his mark Smallwood Junear
Will: his mark Gowthorp

2.1 *Certificate Relating to Tithe of Rape Seed in Storthwaite, 1714.* Reproduced with courtesy of the Hull University Archives. Illiterate farmers signed their name with a symbol because they could not read or write.[110]

110 "Certificate Relating to Tithe of Rape Seed in Storthwaite."

> It being an old established custom, to raise for this purpose a whole country side of men, women, and children, to what is called the *rape cloth*. Everyone is appointed to his station—some to thresh, some bring and place the sheaves, others take away the straw, winnow the grain, &c. &c. It is a day of hard labour and merriment, attended with abundance of good cheer, and plentiful libations of ale, and the evening concludes with dancing and social festivity, &c. &c.[111]

The scene in the famous 1813 painting by George Walker portrays a similar tradition. In *The Costume of Yorkshire, Rape Threshing*, women dressed in bright skirts and white aprons dance with men armed with files to clear and bundle rapeseed. As Baily's observations confirm, the figures in the painting are also engaged in a social scene—in fact, some of the workers even appear to be dancing while working. This reflects the integration of improvement into the culture as much as economy. By telling the story of the planting of rape for oil crushing, we can trace the crop through the diverse English geographies. It was the total value of soil improvement combined with the commodity production of seed that fostered a centuries-long harvest tradition.

In fact, by the beginning of the nineteenth century, the seed catalogues published by nurseries listed rapeseed under the heading of "Seeds to Improve the Land." Rape joined the prestigious list of clover, cow grass, hop clover, white clover, sainfoin, Lucerne, ray grass, spury, Flax, Hemp, Mustard, and Canary. Lists varied between nurseries. The 1812 catalogue published by Dicksons & Gibbs in Inverness listed rape along with tares, lentils, peas, and chicory. A women named Trick Drummond, owner of the Lawn-Market in Edinburgh, listed

[111] John Bailey et al., *General View of the Agriculture of the County of Durham, with Observations on the Means of Its Improvement. Drawn up for the Consideration of the Board of Agriculture and Internal Improvement. By John Bailey* (Richard Phillips, Bridge-street, 1810), p. 146-8.

2.2 *The Costume of Yorkshire,* George Walker, 1813 © University of Leeds.[112]

rape along with Scotch and English Rye Grass and Rib Grass Plantane.[113] There were instances of rapeseed in merchant ledgers already in the eighteenth century, but they seemed to have been occupied with industrial use rather than agricultural improvement. For example, David Young of Perth makes numerous references to the rapeseed trade and primarily split his business between rape and linseed.[114] Yet these records reflect accounts with farmers and oil crushers and do not classify the crop as "improving." In contrast, the popularization of seed catalogues shows that rapeseed was sold to for improvement by tenant farmers and home gardeners who lived on small plots closer to the city and may have only had a fraction of an acre to support an animal or two. These catalogues suggest that *B. napus* was part of a long-term cycle of crop diversification that sparked the categorization of new plants according to their improvement function.

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[112] George Walker, *The Costume of Yorkshire,* 1813 University of Leeds.
[113] "Seed Catalogues ", ed. The University of Aberdeen Special Collections (1812).
[114] David Young, "Merchant, Perth. Journal," in *Court of Session: productions in processes*, ed. National Records of Scotland (National Records of Scotland, 1758).

The question of *B. napus* in improvement can also be understood in the more general contest of debates over the productivity gains from this crop diversification. Quantitative estimates of increased productivity vary greatly between authors and depend upon the archives consulted. However studies of probate inventories show increases as low as about five bushels over the seventeenth century and a surprising stagnation during the eighteenth century when increases rose by only a fraction of a bushel.[115] Other probate studies show a less dramatic discrepancy of a six versus five bushel per acre increase in the seventeenth and eighteenth centuries, respectively.[116] Labour input methods that attempt to estimate the bushels harvested per worker show increases of about 10 bushels per acre during the seventeenth and early eighteenth centuries, however only an increase of five bushels during the following century.[117] Though we cannot know the importance of rape or any other individual crop to these growth patterns, the early chronology of *B. napus* introduction suggests that the crop had a long-term impact.

A broader case for early introduction is argued by historians like Eric Kerridge, Joan Thirsk, and Mauro Ambrosoli, who show that many of the crops used in the Norfolk Rotation and for convertible husbandry were introduced in the early seventeenth century.[118] However as industrial growth was limited by the rate of raw material production even during the early phases of the transition to a coal economy, we must question whether crop diversification alone was sufficient to support long-term, sustained economic and population growth. While technologies

[115] Gregory Clark, "Yields Per Acre in English Agriculture, 1250-1860: Evidence from Labour Inputs," *Economic History Review* 44, no. 3 (1991), p. 448.
[116] Ibid.
[117] Ibid., p. 456.
[118] Eric Kerridge, "Turnip Husbandry in High Suffolk," *The Economic History Review* 8, no. 3 (1956). Thirsk, *Alternative Agriculture: A History from the Black Death to the Present Day*. Mauro Ambrosoli, *The Wild and the Sown : Botany and Agriculture in Western Europe, 1350-1850*, ed. Thirsk Joan, Past and Present Publications (Cambridge England ; New York: Cambridge University Press, 1997).

like clover and legume rotations fix nitrogen, the benefits are subtle and generally have the greatest benefits over time. Yet as even the famous Norfolk Rotation cannot be neatly traced through the landscape in order to reconstruct the dispersal and density of adoption chronologies, it is difficult to correlate the defining technologies of the British Agricultural Revolutions with increases in grain yields.[119] Even the quintessential technologies that define agronomic transformation may have had less of a grand and immediate impact than is often thought.

While *Brassica napus* has not played a big role in the debates about productivity gains so far, eighteenth century observers were in no doubt that the crop could improve soil productivity Near Malton, rapeseed was alternated with turnips by Digby Legard, Esq., who claims to have achieved a threefold improvement from the crops.[120] After sowing rapeseed, Thomas Cussans of Bedbampton near Portsmouth commented that his next wheat crop was very good, and George Maxwell designed a protocol for coleseed that alternated the plant with clover to prepare for beans, wheat and oats.[121] Another good example comes from 1786, when John Doverall wrote in Clifton, Nottinghamshire:

> I fallowed, manured, and limed [a field of eight acres], then sowed rape or cole [and] had a very good crop… In 1787 it was sown with barley and grass seeds… this field has been grazed fourteen years since, chiefly with sheep and some beasts, and has carried a fifth more stock than it would have done previously to the ploughing.[122]

While Doverall offers only an estimate based on unknown field methods, we know that he observed a direct correlation between the use of rape and cole rotations and increased barley yields. In Huntingdon, Richard Parkinson Parkinson believed that the rapeseed crop had proven

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[119] Mark Overton, "Re-Establishing the English Agricultural Revolution," *The Agricultural History Review* 44, no. 1 (1996).
[120] Digby Legard, *High Wolds*, vol. v. 1 Communications to the Board of Agriculture, on Subjects Relative to the Husbandry and Internal Improvement of the Country. (Biblioteca Palatina, 1805), p. 25.
[121] Board of Agriculture, *Communications to the Board of Agriculture on Subjects Relative to the Husbandry and Internal Improvement of the Country*, ed. Board of Agriculture (London: Printed by W. Bulmer for G. Nicol, 1797), Thomas Cussans, 1805, p. 203; George Maxwell, 05, p. 26.
[122] John Doverall, 1805, p. 17.

“to be an advantageous one to the land, as well as a profitable one to the farmer…”[123] If seed was sown at half a peck an acre, it would produce 20 to 40 bushels worth 20 to 50 pounds.

These examples highlight the importance of integrated design innovation. Rather than measuring the increases in bushels per acre during a point in time, the period actors considered the feedback of the agricultural system in terms of the success of future plantings or herds following rape foddering or fallowing combined with other improvements. Regardless of whether a crop increased or decreased over the years in terms of bushels per acre per worker, the overall system became more robust and thus supported greater crop diversity, more plants and animals total, and the promise of a renewable gain year after year despite ongoing harvests.

In sharp contrast, Gregory Clark’s meta-analysis of grain yields per acre per worker shows that the rate of increase in wheat, barley, oat and other yields may have slowed in the later part of the eighteenth century, around the same time that Jethro Tull’s seed drill and the Rotherham Swing Plough had become more widely combined with the Norfolk Rotation and Convertible Husbandry. “Thus the information about payments to labour in agriculture suggest that the bulk of the substantial rise in agricultural productivity which occurred between 1300 and 1850 is located in the years before 1770,” writes Clark. “The agricultural revolution thus pre-dates the industrial revolution rather than complimenting it as the consumption-based estimates would suggest.”[124] In contrast, my own case study of rapeseed in improvement points to a different set of indicators of productivity. The robust system that supported greater diversification in terms of the number of crops and the sorts of ways they might be incorporated

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[123] R. Parkinson, *General View of the Agriculture of the County of Huntingdon*, ed. Board of Agriculture (Phillips, 1811), p. 137-9.
[124] Clark Gregory, "Yields Per Acre in English Agriculture, 1250-1860: Evidence from Labour Inputs," *The Economic History Review* 44, no. 3 (1991), p. 459.

points to a more reliable, renewable, and resilient system of farming that continued to develop into the nineteenth century.

III. Integrated Systems of Production

The relationship between oilseed and textile manufacturing raises questions about the industrial drivers of crop innovation. Rapeseed oil was used to finish a range of raw textile materials, including wools and cottons for industrial weaving or home spinning.[125] In *The English Housewife* published in 1631, readers are given careful instruction to lay their wool in a flat bed and "take the best Rape oyle, or for want there-of either well (rayd?) red goose grease or swines grease, and having melted it with your hand, sprinkle it all over your wool and work it very well into the same: then turne your wool about, and doe as much on the other side."[126] At the industrial scale, certain cloths were treated and finished with mixtures of oils, while some cloths and manufacturing systems relied upon a single oil. The integration of rape oil into this system took time, and it was this innovation that would drive the spread of the golden rapeseed across England.

Joan Thirsk remains the only scholar to integrate rapeseed into a review of alternative rotation crops.[127] Yet Thirsk dedicates only a few pages to rapeseed in *Alternative Agriculture* and a short chapter to coleseed in *English Peasant Farming*. One of Thirsk's greatest

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[125] Joan Thirsk, *Seventeenth-Century Economic Documents*, ed. J. P. Cooper (Oxford: Clarendon Press, 1972), p. 445-6.
[126] Gervase Markham, *The English House-Wife Containing the Inward and Outward Vertues Which Ought to Be in a Compleat Woman, as Her Skill in Physick, Chirurgery, Cookery, Extraction of Oyls, Banqueting Stuff, Ordering of Great Feasts, Preserving of All Sort of Wines, Conceited Secrets, Distillations, Perfums, Ordering of Wool, Hemp, Flax, Making Cloath and Dying; the Knowledge of Dayries, Office of Malting, of Oats, Their Excellent Uses in Families, of Brewing, Baking*, And now the ninth time much augmented, purged, and made most profitable and necessary for all men and the general good of this nation. ed., Goldsmiths'-Kress Library of Economic Literature; (London: Printed for Hannah Sawbridge ...,c1683., 1683), p. 126, img 44.
[127] Thirsk, *Alternative Agriculture: A History from the Black Death to the Present Day*. *English Peasant Farming; the Agrarian History of Lincolnshire from Tudor to Recent Times* (London: Routledge & K. Paul, 1957).

contributions in this short literature is the history of a clothier named Benedict Webb, who set out for France in search of a reliable substitute for Spanish olive oil in the early seventeenth century. When he returned with rapeseed and designs for an oil mill, English farmers soon had a reliable buyer for crops of rapeseed.[128] Though Thirsk does not consider the environmental history of rapeseed nor entertain its possible impacts on the soil, her history of England's early economic investment in the plant illustrates its importance as a lucrative cash crop due to Webb and his competitors. Her work allows a careful reader to understand how seventeenth-century farmers placed rapeseed in the right place at the right time to help improve soils and grain yields.

In England, it was not until the Spanish Empire began to leverage olive oil supplies in the 1540s that trade dependency became a concern. Just before cereal yields began their initial increase, rape oil was grown at King's Lynn in 1551 to supply St. Radegund's priory in Cambridge.[129] This first documentation of rapeseed introduction correlates nicely with the first increases in the price of Spanish olive oil. Prices of olive oil grew by a third between 1542 and 1549, while olive oil supplies were entirely jeopardized in the 1570s when political tensions with Spain came to a head. Because Spain was now selling olive oil to colonies in the West Indies, it threatened there would be long-term shortages in Europe that would prevent future shipments to England.[130] Following early trials of the seed oil press in King's Lynn, a patent that covered the production of oil from seeds was issued in 1565, and another device for making oils for English clothiers was developed in 1571. Then in 1572, a parliamentary bill was introduced to spur the making of oils in England. Waves of protestant immigrants brought new technologies for finishing cloth, and Queen Elizabeth and her Privy Council issued numerous patents for seed

[128] *Alternative Agriculture: A History from the Black Death to the Present Day*, p. 74.
[129] Ibid.
[130] Ibid., p. 74-9.

"oyle" production during the last quarter of the sixteenth century. A handful of projects began to test new planting and seed crushing technologies.

Though many farmers took the liberty of growing and even milling oil without having any official rights via a patent, o*ne of the earliest sources to identify the benefits of rapeseed on future corn crops was the King James Edict that officially created Webb's oil monopoly in* 1624.[131] *According to the edict:*

> *…besides the seting of many of Our poore Subjects on worke, and the great enriching of much barren land in this our Kingdome, for that the said Oyle-seeds doe best prosper upon dry and sandy grounds, which being otherwise of small use and profit, will (after some few yeeres imployment in Tillage for the said Oyle-seede) become fruitful for Corne and glue good returne to the Husbandman.*[132]

The edict thanked Webb for his discovery of rapeseed oil while "hauling his trauell beyond the Seas," and confirmed that rape oil helped offset dependency on Spanish olive oil.[133] In fact, Webb had returned from France for some twenty years before he applied for the patent, and by the time the edict was announced, his technology had already begun to prove its usefulness.[134] The petition to the King notes that rape oil was "far better for the use of clothing than that which is yearly brought out of the low countries and as useful as the Spanish oil yearly imported into this Kingdom."[135] Though the invention never made Webb rich, and much of his correspondence mentions his debtors and even his pleas to family to cosign, rapeseed was generally profitable because is made land that was otherwise worth a small price more fruitful

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[131] Ibid.
[132] Sovereign England and Wales and King of England James I, "James, by the Grace of God, King of England, Scotland, France, and Ireland, Defender of the Faith, &C. To All to Whome These Presents Shall Come, Greeting Whereas Our Welbeloued Subiect, Benedict Webbe, of Kingeswood, Clothier, Hauing in His Trauell, Obserued a Kinde of Oyle to Bee Made of Rape-Seede," ([London :: F. Kingston Ann Arbor, MI Oxford (UK) :: Text Creation Partnership], 1624), Manuscript 52 and 59.
[133] Ibid.
[134] "Letter, Acquittances and Receipts, Agreements, Mutual Releases Relating to Business Affairs of John Smyth, 1614-1626, Including Many Letters from Sir William Throckmorton, of Clearwell, and Benedict Webb, of Kingswood," in *Smyth of Nibley Papers* (1614-1626), Manuscript 52 and 59.
[135] Ibid.

for corn.[136] By setting up a centralized mill that pressed rapeseed collected from many growers as well as rapeseed grown on farmland owned by the mill, a stable industry was born. At first, clothiers used rape oil only on the cheapest cloth, but by 1626 most of the industry relied entirely upon it.[137] Even though rapeseed had been previously imported, grown, and pressed by many farmers, it was Webb through his industrial-scale mill who was given credit. Through his monopoly of the rape oil industry, Webb created a secure market for rapeseed plantings for a wide range of growers.

Born to a clothier family in Kingeswood of Wilte in 1563, Webb entered a bound apprenticeship with a French linen draper at the age of 16. After his five-year apprenticeship in France, Webb returned to England and set up shop in Taunton, Somerset, where he developed a novel technique for making a multicolored cloth, which quickly became fashionable. In 1605 Webb was sent to France as an official representative of the Crown to negotiate better terms for English cloth merchants, and it was during this trip that he studied rapeseed-milling and cultivation in order to bring back a model of an oil mill. Upon Webb's return from France, a trial mill was established at Kingswood, where he began to plant rapeseed.[138]

Over the course of about a decade, Webb quickly overcame deep prejudices shared among clothiers, some of whom believed that rape oil caused worms to grow in fabric.[139] Webb's most important advantage was that he could undercut the price of olive oil. His rape oil could be mixed with other oils, but it cost only 2 shillings a gallon while Spanish olive oil climbed upwards of 3 shillings and 8 pence.[140] But it wasn't until 1618 that production of oil

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[136] "Six Letters to John Smyth of Nibley from His Uncle Benedict Webb of Kingswood (near Wotton-under-Edge), Clothier, 1630-1631, and His Cousin Benedict Webb Junior, 1632, with Transcripts," in *John Smyth of North Nibley* (1630-1632), p. 15/G7/3.
[137] Thirsk, *Alternative Agriculture: A History from the Black Death to the Present Day*, p. 74.
[138] Ibid.
[139] Thirsk, *Seventeenth-Century Economic Documents*, p. 499.
[140] *Alternative Agriculture: A History from the Black Death to the Present Day*, p. 73-8.

was consistent enough to displace imports of Spanish olive oil to London and Bristol. Thirsk dedicates a few pages to Webb's monopoly:

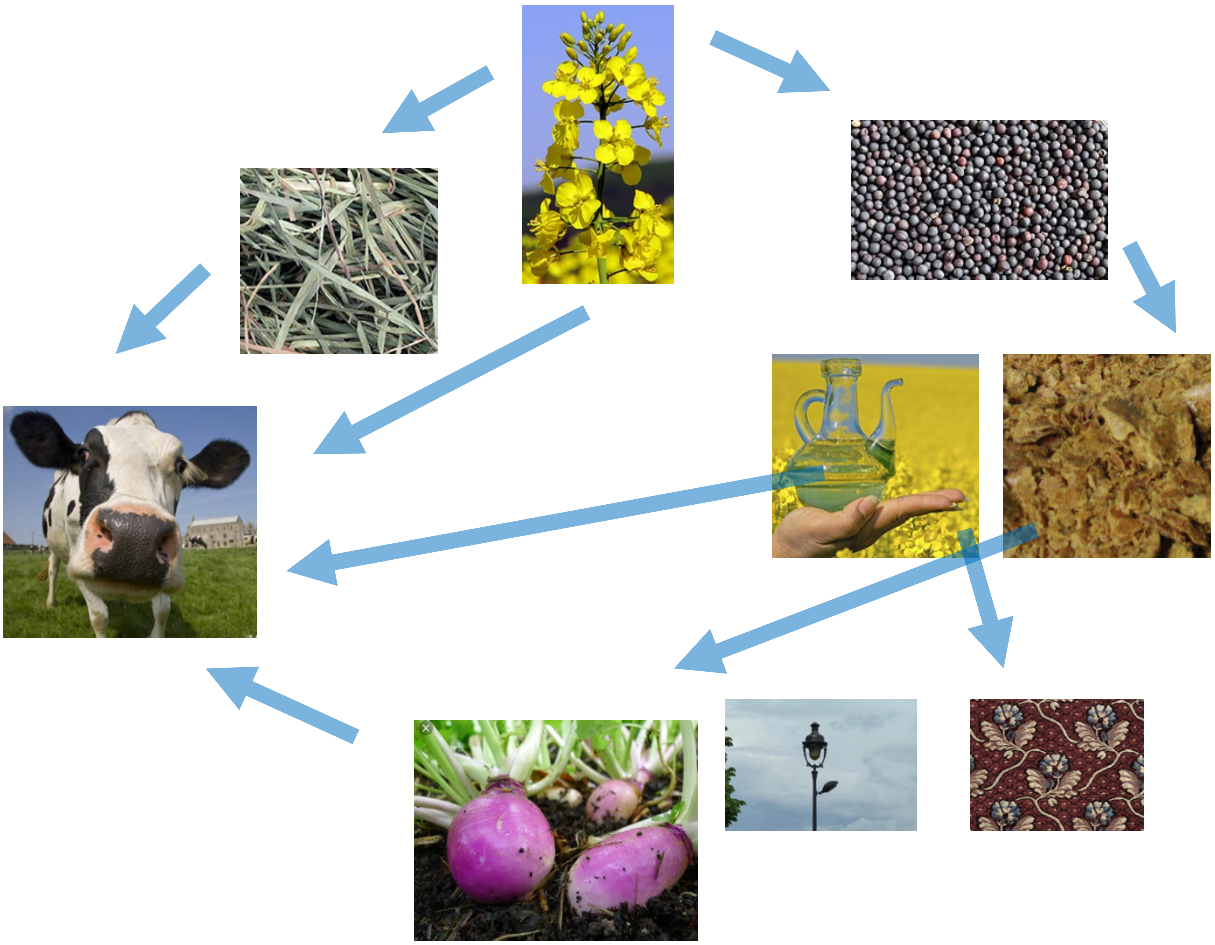
> By 1621 the production line at the mill was operating smoothly, and in 1626, 20 gallons of oil were flowing daily. By that time [Webb's] land for rapeseed in the Forest of Dean amounted to 550 acres, and [he] was a substantial farmer, as well as a clothier. If all 550 acres had been sown at one time (which is unlikely), it would have produced 1,650 bushels (3 bushels per acre) or 165 tons of oil.[141]

This was a lucrative business—Webb likely made about 345 pounds a year off his holdings. But this industry spurred a much larger market that encouraged farmers throughout England to take up growing rapeseed.

Webb's monopoly also spurred allegiances between growers and competing mills. His monopoly rights were deeply resented and hotly contested by other family businesses, and this encouraged the formation of insular cohorts of local rapeseed producers. Webb's biggest competitor was Richard Warner, a soap boiler in Bristol, who introduced rape oil to the production cycle of a second major industry—that of soap making. Warner first established a single oil mill at Caerleon in Monmouthshire and primarily sold his oil in Bristol, which was one of the clothier markets for Webb's mill. Warner's mill was built on the lands of the Earl of Pembroke, who likely offered help as a courtier-projector behind the scenes by promoting Warner's enterprise.[142] This fueled community building as much as competition as Warner expanded into Wales and Gloucestershire and set up a family cloth making business that directly competed with Webb. In the 1640s his enterprise was primarily exporting cloth and milling oil, although rapeseed oil continued to be used in soaps.

When Webb accused Warner of stealing his seeds and technology, Warner claimed to have his own sources of seed. He claimed that he learned the business from John Pryce of

[141] Ibid.
[142] Ibid., p. 76.



2.3 *B. Napus in the Eighteenth Century Production Cycle*, Amy Coombs. In the eighteenth century, the yellow flowering Brassica Napus (top) was used to produce oilseed (top right) that was then crushed for oil and seed meal (middle right). The oil was used for lighting and textile finishing (bottom right). The meal was incorporated into soils as a manure for turnips and other crops (bottom). Both the meal or cake and the turnips were used as livestock feed (middle left). Plant stalks were also dried for winter feed for livestock (top left).

Redriffe (Rotherhithe) who had been making oil with others for twenty years. While Webb and Warner entered into a series of lawsuits, each claiming the other stole proprietary technology, oil mills popped up like weeds in other areas of the kingdom.[143] This suggests that rapeseed's role in both textile and soap manufacturing was a continuing factor in the story of Brassica diffusion in the late seventeenth century. As different markets carved out niches and competed, farmers expanded rapeseed into new geographies and maintained their holdings through a supply stream.

Ultimately it was Webb who succeeded in earning the patent rights to market domination. In Webb's 1624 request to the Crown for a patent, his petitioner William Smithesbie writes that the oil mill "setteth many thousands of poor people on work," and "brought small comfort to the husbandman." Smithesbie even claims that the invention brought "so useful and rich a commodity to your kingdom as the like has seldom been really effected."[144] On the 28th of November 1624, the Court at Newmarket asked the Attorney General to prepare a bill for his Majesty's signature containing a grant to the petitioner for 14 years, as they had desired. This alone does not shed light on the magnitude of rapeseed disbursal. But as Webb's patent heightened the competition for rapeseed, it is a good indication of the crop's ecological impact.

Sustainable farming strategies are most influential when used over the course of many years because the benefits are small and cumulative. It is thus important that rapeseed was introduced through small patented trials and then promoted by industry over a twenty or thirty year time period before monopoly rights were granted. While rapeseed for oil was certainly not the only beneficial new technology introduced to early modern fields in the late sixteenth century, it is important that introduction occurred early in the cycle of agricultural growth and

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[143] Ibid., p. 74-9.

[144] Thirsk, *Seventeenth-Century Economic Documents*, p. 220-21; "Letter, Acquittances and Receipts, Agreements, Mutual Releases Relating to Business Affairs of John Smyth, 1614-1626, Including Many Letters from Sir William Throckmorton, of Clearwell, and Benedict Webb, of Kingswood," Manuscripts 52 and 59.

development. In fact, rapeseed may have been among the first of the beneficial fodders and green fallow plants introduced at the large scale. But its early success in England depended upon its incorporation into a larger system of textile production. By the time that agricultural yields began their steepest climb in the early eighteenth century, rapeseed had spread through England due to Webb's mastery of a French craft that changed the English economy.[145]

As to the size of the early seventeenth textile century market, there were 100,000 people in 13 counties of Wales who earned a living as clothiers or textile makers. There were 10,000 to 15,000 clothiers in each of the 100 villages in Yorkshire and the 57 villages around the Barony of Kendal.[146] These estimates focus primarily on the early cotton market, and do not represent other textile makers or soap makers. However we know that the oil was also used for local lighting projects. Wisbech in Cambridgeshire shipped 1,000 tons of rape oil annually by 1719, which is why this small town of only 2,000 people had street lighting in 1700 when larger cities like Leicester waited until the 1760s for oil lamps.[147] Rape oil lamps gradually appeared in other small villages; they are identified by an inverted design that allowed the oil to drop from the top of the lamp through a gravity pull system. In contrast, many lamps of the time used wick technology that pulled oil up from the bottom of the lamp.

The market for rape oil was so lucrative that one observer called it the most profitable of national industries. In 1715, Aaron Hill, who wrote librettos for George Frederic Handel, saw Webb's legacy as a sign that money could be made through innovation in the oil industry.[148] In

[145] Joan Thirsk, *Economic Policy and Projects : The Development of a Consumer Society in Early Modern England* (Oxford: Clarendon Press, 1978), p. 71-2; Joan Thirsk *English Peasant Farming; the Agrarian History of Lincolnshire from Tudor to Recent Times*, p. 128.
[146] Joan Thirsk *Seventeenth-Century Economic Documents*, p. 445-6.
[147] Joan Thirsk *Alternative Agriculture: A History from the Black Death to the Present Day*, p. 78.
[148] Aaron Hill, *An Account of the Rise and Progress of the Beech-Oil Invention : And All the Steps Which Have Been Taken in That Affair, from the First Discovery to the Present Time : As Also, What Is Further Design'd in That Undertaking*, Goldsmiths'-Kress Library of Economic Literature ; (London: [s.n.], 1715), p. 23.

an attempt to displace rape oil with a similar product from Beech tree fruit, the musician and agriculturist carefully reviewed the market. In an investment solicitation for his Beech-oil invention, Hill likened the rapeseed oil market to a kingdom:

> And he who fist brought into Practice this Rape-Oil Trade, wanted nothing but the Prudence of soliciting a Patent, which he was undoubtedly entitled to, to have made himself the Master of as great a Fortune as any in the Kingdom. Hundreds yearly at this very Day get Estates by that Trade, which at Four Shillings a Bushel produces less Oil, and far worse, than our Beech-Mast, which can never cost Six Pence per Bushel… The Land that bears this Rape is let at an extraordinary Rent, and cultivated at a vast and constant Expense.[149]

According to Hill, the rape oil market had become so profitable that rents for fields had spiked. Farmers who tried to negotiate the planting of rape for seed faced extra costs from landlords for two reasons—the crop was potentially exhausting and thus devalued the price of the land, and the lucrative sales supported higher rents. Yet this economy relied as much on small-scale producers as large-scale growers and continental imports. For example, in 1714 James Hart traveled from Scotland to London and noted in his travel diary that fields of rapeseed spanned 20 to 30 acres each in Easingwold, where farmers grew the plant to feed cattle and to sell to the oil industry.[150] By the early nineteenth century rape seed purchases as well as payment for the planting of rape appeared in account ledgers kept for small, rural farms, which suggests that small-scale planting persisted through the century.[151] However according to Thirsk, rape fields as large as 4,000 acres were documented by the mid seventeenth century.[152] English demand for rapeseed was high due to the importance of oil in economic development in the seventeenth, eighteenth, and nineteenth centuries.[153]

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[149] Ibid.
[150] Thirsk, *Alternative Agriculture: A History from the Black Death to the Present Day*, p. 78.
[151] "Farming Accounts Book," in *Stricklands of Boynton Hall, Family and Estate Collection*, ed. Beverly Treasure House (Beverly Treasure House Archive 1809).
[152] Thirsk, *Alternative Agriculture: A History from the Black Death to the Present Day*, p. 74-8.
[153] *Seventeenth-Century Economic Documents*, p. 445-46.

However the size and structure of the oil market is not the only consideration when exploring the ecological impacts of rapeseed and its role in fighting soil disease and increasing fertility. Rapeseed was not only valuable because it could be sold to an oil mill. It was also used as series crop and then fed to cattle or sheep. The use of rapeseed as a cover crop made it possible for English farmers to grow wheat, barley, and corn on sandy and expended soil. The plant was a lucrative series crop that increased the value of the fallow cycle in two ways—first, unlike most other fallow plants, rape seeds could be sold directly for a profit and were sometimes produced by the very plants that animals browsed through a double-use of the field, and second, rapeseed was quickly recognized for its ability to improve the soil and thus increase profits by increasing yields. The soil benefited from both the planting of rapeseed and the benefits of manuring from grazing, thus integrating three system of production—fodder planting, livestock farming, and seed production.

This was a step forward for the soil. Depending on the land management practices, the historical English and Scottish system suffered from a lack of nutrient integration during the seventeenth and eighteenth centuries. Even if the scale of production was smaller, the separation of manure from arable acres was sometimes a problem in common fields. Even when the town herd was relocated from the grazing commons to manure arable strips, there were rarely enough animals to benefit the private fields in the region. Rotations through common arable were more rare due to the labour costs of planting fodder.[154] Only the wealthy farmers could afford to hire the common herd to visit their private crop fields. The Saxon three course cycles that persisted in some locations only rotated bare fallow, grazing pasture, and crop fields over the land in long-term cycles. Ley husbandry posed a similar problem in that self-regenerating meadow took

[154] Eric Kerridge, *The Common Fields of England* (Manchester, UK ; New York : New York: Manchester University Press ; Distributed exclusively in the USA and Canada by St. Martin's Press, 1992), p. 71-83. .

years to become established, and this lengthened the cycle of land conversion from planted crop to permanent or semi-permanent pasture. Until convertible husbandry became more widely practiced due to rotation and fodder innovation, it was unlikely that a farmer would see the cycle of pasture to crop land in his or her lifetime. In contrast, new fodders combined with drills and horse hoes greatly accelerated this rotation and allowed farmers to control the planting of fodder and integrate cycles of grazing into arable. The use of byproducts like seed meal as a manure served to recycle a production output back into the soils to increase fertility.

This illustrates the incentive to grow rapeseed on large plots even despite the high rents Hill mentions. The early history of rapeseed as an oil plant thus reflects a changing tide in agriculture that had regional impacts. Not only were a wide variety of new crops imported for trial, but farmers began to select the best seeds to drill, which gave rise to robust crops. These benefits likely contributed small gains to yields, but the benefits accumulated in the soil over time. Thus, as rapeseed began to spread more widely, English farm systems would have been primed for the best results.

The abundance of oilseed crushing mills offers the greatest evidence for the industrial integration of *B. napus* into the local economy. Original designs for a wind powered rapeseed crushing mill built in 1755 in Wakefield for a Mr. Roodhouse illustrate the apex of period engineering and the integration of passive energy to crush *B. napus* into oil.[155] Remnant rape oil mill designs are rare, and the complexities of a comparative study between mill types exceeds the scope of the present chapter. However the designs illustrate a three wheel complex that may have been use to both grind the seed into a cake and then break the cake into a powder. The large windmill tower shows no sign of additional energy inputs such as a horse pull.

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[155] "Original Desinge for the Rape-Oyl Mill at Wakefield," in *GB 117*, ed. The Royal Society (1755).

In *History of Seed Crushing in Great Britain*, Harold W. Brace cites about 640 similar seed crushing mills in the nineteenth century. Brace believes that most of the mills served to crush *B. napus* into oil, though some also crushed bone, flax, hemp, linseed, and other raw materials.[156] From Brace, I extracted about 600 functional mills used to crush oilseed in England, Scotland, and Wales between 1790 and 1865. By using ArcGIS to plot disbursal, a concentrated nexus of mills appeared on the East Coast with a broad scattering of mills through most parts of Britain.[157] This supports evidence found in the Parliamentary Papers Database that seed was imported from the continent to crush. While it is not possible to estimate the relative amount of seed imported and grown in any community, the Hull History Center archives offer at least anecdotal evidence that confirms continental imports of rapeseed to Britain. The Records of Rose Downs and Thompson Ltd.—manufacturers of general engineering products, oil machinery, and food processing equipment—contain a manuscript of historical imports tabulated by professional historians working in the twentieth century.[158] The paper lists eight residents in Kingston Upon Hull who imported between 250 and 1,230 quarters of rapeseed in 1690.[159] In total, 4445 ½ quarters were imported during 1690. However the manuscript omits methodologies and cites no primary sources. We cannot say why England was unable to meet its own demand for Brassica seed and relied upon continental imports. Regardless of whether *B. napus* was more often grown as fodder or for soil improvement, with the seed offering secondary income, or was rather

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156 Harold Witty Autor Brace, *History of Seed Crushing in Great Britain / Harold W. Brace* (London: Land Books Limited, 1960), p. 99-158.

157 Unfortunately due to COVID19 I was unable to gain access to the ArcGIS labs on campus during the end of winter, spring, and summer quarters. Though I invested a lot of time in this project, I was unable to finish the final maps. See Appendix 2 for a map of the first 59 mills.

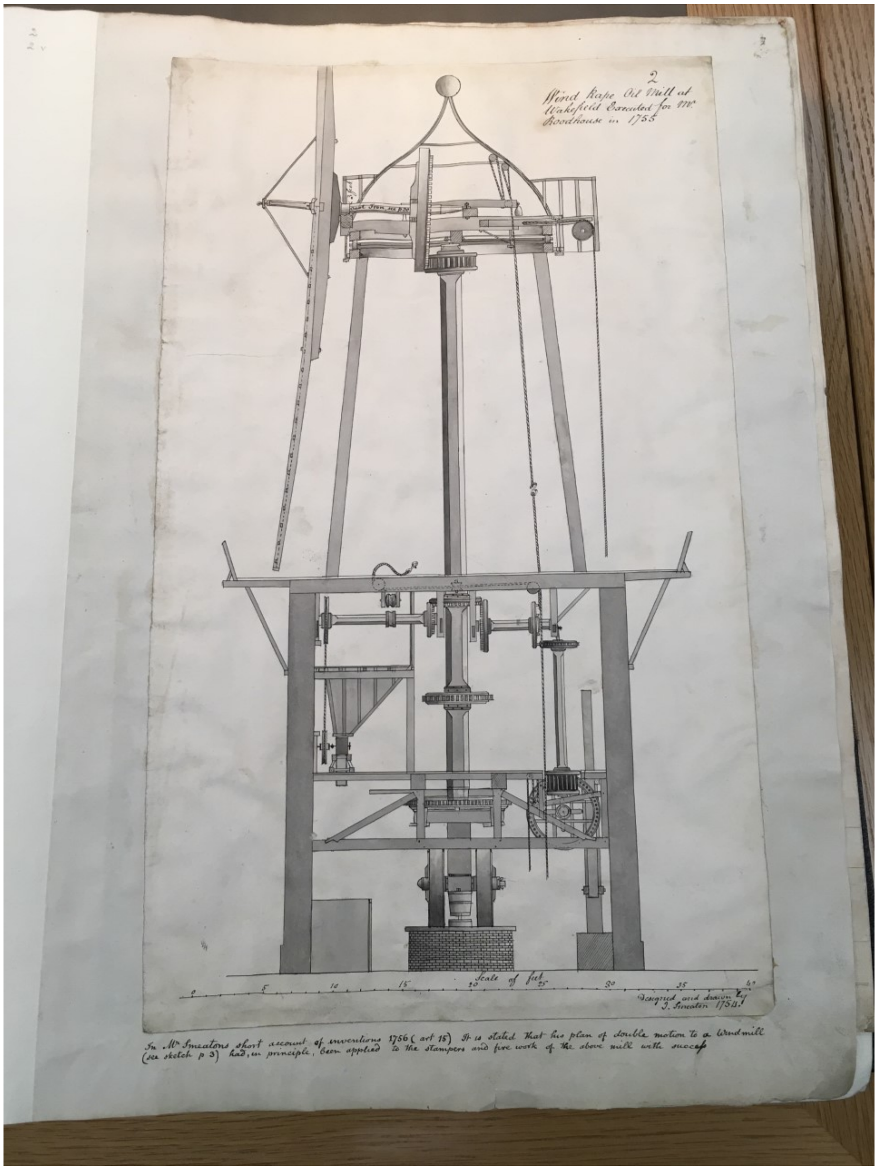
158 Rose Downs and Thompson, "Rape-Seed Imported to Hull," in *Records of Rose Downs and Thompson Ltd*, ed. Hull History Centre (1690).

159 Ibid.

produced at the larger scale but exported back to the continent as part of a reciprocal trade dependency, it is clear that there was plenty of meal left from the press to serve as manure.

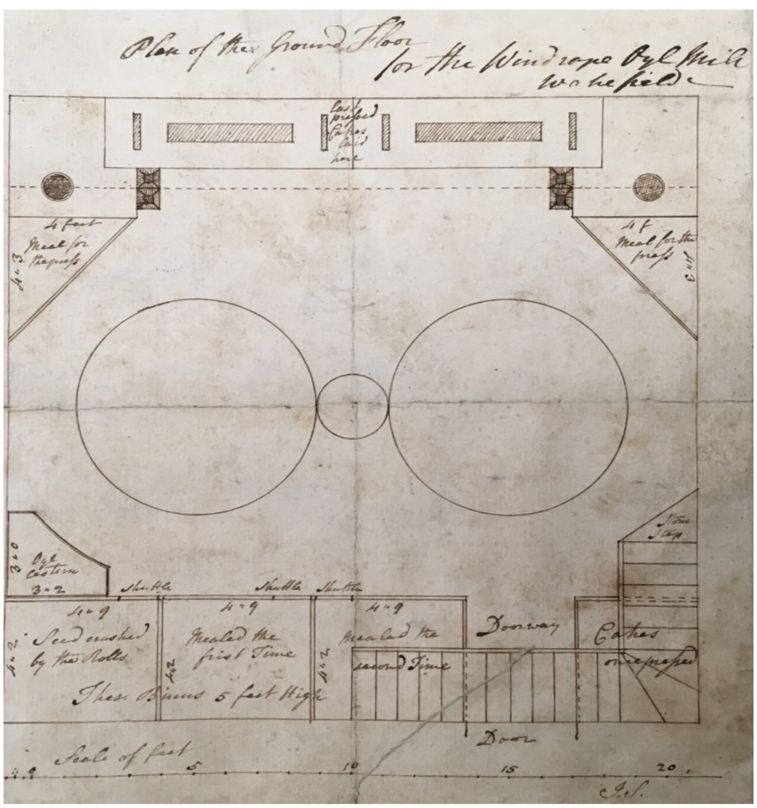
Though we do not know the country of origin of the rapeseed imports or if they were used for oil crushing or also planting, it is clear that the cake and dust from the oil press was recycled back into local fields. In 1733 William Ellis describes how rape cake and dust left from oil crushing was bagged and sold to farmers as a manure.[160] Ellis writs "…Farm Neighbors that have equally contributed to the purchase of twenty twelve-bushel sacks, which they alternately fill with Chaff &c. and carry to London in their Wagons, where they again load with some of these as a dressing for their land…".[161] We also know that this meal was returned to the soil in a sustainable cradle-to-cradle design, which moved resources through one production cycle, or cradle, and into the second via recycling. For example, 1811 William Gooch similarly described

[160] Ellis, *Chiltern and Vale Farming Explained : According to the Latest Improvements*, p. 398-9.
[161] Ibid.



2.4 Rapeseed Mill, Wakefield, United Kingdom, 1755. Reproduced with the permission of the Royal Society. Original designs for a wind powered rapeseed crushing mill built in 1755 in Wakefield for Mr. Roodhouse.[162]

[162] "Original Desinge for the Rape-Oyl Mill at Wakefield."



2.5 *Rapeseed Mill Grinding Plans, Wakefield, United Kingdom, 1755.* Reproduced with the permission of the Royal Society.. Grinding plans for a Wakefield rapeseed mill. The top image shoes the exterior mill design, and the drawing on the bottom suggests that two grinding ring gears may have been used to crush seed.[1]

a technique for drilling ten bushels of rape dust with wheat eight inches deep into the soil. The thirty-five acres consisted of a thin stapled chalky loam on a sterile yellow chalk bottom covered with clover seed stubble. The use of the dust was said to diminished the mildew that damaged two prior plantings on the same poor soils.[163] Thus, the long history of *B. napus* in improvement suggests that agricultural development happened through an integrative process that utilized production byproducts as part of a cradle-to-cradle design.

While nascent industrial and integrated improvement practices were both concerned with economic development, they were predicated upon fundamentally different pedagogies. Like other proponents of larger scale monoculture and intensification, Tull believed that agricultural improvement separated the men from the beasts and the civilized from the pagans. He wrote "the bristled animals broke up the ground because they used to find their food there by digging. Men till it because they find tillage procures them better foods than acorn."[164] Tull expanded upon the story of Ceres—the pagan goddess invented by the primitives—who first taught the art of tillage. "With this fable they were so well pleased that they never attempted to improve that art, lest they should derogate from the Divinity of Ceres, in supposing her invention imperfect," he wrote.[165] If nothing else, Tullian husbandry was less stressful for the farmer than field preparation by handwork.[166] Perhaps this is the obvious story to tell when tracing the mechanical innovations that shaped and re-shaped the plough, drill, and hoe over time. But if we take a step back to understand environmental impacts of repeated rapeseed plantings without

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[163] Gooch, *General View of the Agriculture of the County of Cambridge*, p. 130.
[164] Jethro Tull, *Horse-Hoeing Husbandry: Or, an Essay on the Principles of Vegetation and Tillage. Designed to Introduce a New Method of Culture; Whereby the Produce of Land Will Be Increased, and the Usual Expence Lessened. Together with Accurate Descriptions and Cuts of the Instruments Employed in It* (A. Millar, 1751), p. 278-9.
[165] Ibid., p. 279.
[166] "The Industrial Revolution: Jethro Tull ", https://sites.google.com/a/imagineprep.com/theindustrialrevolution/inventors/jethro-tull.

manure, fallow, or rotation, an otherwise beneficial improvement technology risks promethean consequences due to the Tullian design.

Tull's exclusion of fertilizers, crop rotation, and fallow was based on his over-confidence in deep tillage. "Earth was the food of plants insofar as the particles were finely divided. Water, air, and fertilizers were required only to convey or loosen the particles… Pulverization of the soil was the clue to all the mysteries of successful husbandry," writes Wicker.[167] However new fodder introductions were no more a panacea than better tillage. At best, most fodders had a slow and cumulative benefit.[168] Even clover was thought to fatigue the soils in some areas where the crop spread clover disease.[169]

The case study of *B. napus* is important for tracing the integration of these two agricultural innovations. Foddering, green fallowing, and rotations regenerated soils strained by the intensified plantings of cash crops made all the more profitable due to the better spacing of plants in drilled rows. The mechanized disbursal of both seed and manure by drills not only supported more rapid field preparation, it also overcame the problems of patchy broadcast seeding which increased competition for water, nutrients, and growing space between plants while running the risk of erosion in less densely seeded patches.

In conclusion, it was oilseed for textile production that provided the original impetus for early modern *B. napus* introduction. Farmers quickly discovered other uses for the crop for soil regeneration, and in the eighteenth century these foddering and fallowing designs were coupled will drilling, horse-hoeing, and deeper tillage. The relationship between the drills and the mills highlights the importance of late eighteenth-century improvement as a form of integrated design.

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[167] Wicker, "Note on Jethro Tull Innovator or Crank?," p. 47.
[168] Kenneth Pomeranz, *The Great Divergence : Europe, China, and the Making of the Modern World Economy*, Princeton Economic History of the Western World. (Princeton, N.J.: Princeton University Press, 2000), p. 198, 210.
[169] Ibid., p. 198.

It was not just the small-scale combining of the many new planting and manuring technologies described by the British improvers that diverged from Tullian and other industrializing practices. Rather, crop production and oil crushing were tied to mechanisms of pest control and soil regeneration. *B. napus* was only one available manure, however in localities where rapeseed was imported for crushing, this ensured the completion of the resource loop even despite the extra-local production input. At least part of the energy used for transport was returned to the environment in the form of soil regeneration. In the next chapters I will describe this process at length.

CHAPTER THREE: Rapeseed and Turnip Combining in Convertible Husbandry for Increased Land Use Efficiency

I. Introduction

"If the tale of agricultural improvement could be told in any two syllables, it would be those which spell turnips," wrote W. Wealands Robson in the opening of his 1890 article *Turnip Husbandry*.[1] By growing winter feed on land that would otherwise lay unproductive during years of regeneration, turnip agriculture increased herd size and manure inputs. This reduced the need for fallow, allowed more permanent pasture and grassland to be converted to arable, and increased future yields of grain crops on soils that needed a recharge after generations of planting. Simply put, "turnips make manure, and manure makes corn," wrote Robson.[2] No longer were farmers forced to reduce herd sizes to prepare for the cold, dark months by slaughtering large numbers of animals to salt or smoke. And along with the higher yields from the increased manure, turnips put fresh beef and mutton on the tables by providing white bulbs that stored well through winter and a drought and frost hardy fodder that thrived through the late summer to fall when natural grasses began to wane. "There could not be any such thing as Christmas beef in the first quarter of the last century," wrote Robson. "We talk fondly of roast beef being true old English fare. We might rather have termed it rare old English fare, for our fathers only knew it from Midsummer to Martinmas."[3]

This description of turnip farming highlights the economic development enjoyed by England due to its movement towards convertible husbandry. The British Agricultural Revolution is often described by the re-sectoring of a growing urban population fed by a

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[1] W Wealands Robson, "Turnip Husbandry," *The Monthly chronicle of North-country lore and legend* 4, no. 37 (1890), p. 101-2.
[2] Ibid.
[3] Ibid.

relatively stable agricultural sector. While many craftsman and manufacturers may have grown some portion of their food in the seventeenth and eighteenth centuries, the agricultural sector gradually supplied larger cities full of rented flats and factory workers not to mention corn export laws that may have helped England balance imports of grain and meat from Island. As the chronologies of yield increases and the environmental harms and benefits of mechanization are hotly debated, the British Agricultural Revolution is often defined by the simple fact that a burgeoning industrial sector continued to expand without the need for proportionate expansion of arable acreage to support the larger landless population. As Robson concluded, "How could the present population be found with animal food except by means of turnips?"[4]

Despite the simplistic textbook definition of convertible husbandry as the rotation of grazing and arable, a comprehensive model of the practice is difficult to pin down due to the diversity of descriptions in the primary historical and secondary literature. But as I will illustrate in this work, convertible husbandry can be well described from the period sources by the more efficient relationship that Robson invokes between increased soil productivity and land use efficiency from the manure contributions of larger herds supported by fodder or feed innovation in place of fallows, self-sustaining meadows, marsh, or moor. Though other fodders made important and often overlooked contributions, historians have long used turnips as an indicator of the transition to convertible husbandry and the privatization of land tenure thought necessary for the incorporation of new crops. In fact, by the early nineteenth century, many farmers identified lands suitable for convertible husbandry by the ability of the soil to support turnips. "It is plain that the sorts of lands that are the most adapted to the practice of convertible husbandry are those

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[4] Ibid.

of the loamy kinds, which are not too strong for the growth of turnips," wrote R. Baldwin in his 1807 *The Complete farmer; or General dictionary of agriculture and husbandry*.[5]

C. Peter Timmer emphasized the importance of the turnip to economic transformation by citing the acceleration of convertible husbandry as the beginning of the British Agricultural Revolution. Timmer wrote that in the late eighteenth century "…the turnip, grown on the fallow of the open fields, opened farmers' eyes to the possibilities of convertible and alternate husbandries which were the real basis of the revolutionary increase in agricultural production."[6] In his 1969 essay *The Turnip, The New Husbandry and The English Agricultural Revolution*, Timmer claimed that the accelerating growth of turnip husbandry for convertible farming in the latter half of the eighteenth century was so instrumental as to have "mark[ed] the opening of the Agricultural Revolution just as surely as factory production mark[ed] the dawn of a new industrial age."[7] Eric Kerridge similarly relied on evidence of early turnip introduction and convertible husbandry to propose his competing model of an earlier agricultural revolution.[8] "In the middle of the seventeenth century there suddenly took place in High Suffolk an agricultural revolution by the introduction of turnip husbandry, that is, the field cultivation of turnips…" he writes.[9] Regardless of the chronology of transformation, the turnip has long taken center stage

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[5] R. Baldwin, *The Complete Farmer; or, General Dictionary of Agriculture and Husbandry: Comprehending the Most Improved Methods of Cultivation; the Different Modes of Raising Timber, Fruit, and Other Trees; and the Modern Management of Live-Stock: With Descriptions of the Most Improved Implements, Machinery, and Farm-Buildings.*, 5th ed. ed., ii vols., vol. i (London: (London): Printed for R. Baldwin, Rider and Weed), 1807), Section L, LAN, H2 (no page numbers).
[6] C. Peter Timmer, "The Turnip, the New Husbandry, and the English Agricultural Revolution," *Quarterly Journal of Economics* 83, no. 3 (1969), p. 395.
[7] Ibid., p. 383. Timmer references J. D. Chambers and G. E. Mingay, who concluded that it was the acceleration of convertible husbandry along with enclosure in the latter half of the eighteenth century that marked the opening of the Agricultural Revolution just as surely as factory production marks the dawn of a new industrial age.
[8] On p. 107 Kerridge quotes J. A. Yelling's point that "Had there been convertible husbandry in common fields, the advantage attaching to enclosure would have been much less or even non-existent."Eric Kerridge, *The Agricultural Revolution* (New York: A.M. Kelley, 1968), p. 49-50, 219. J. A. Yelling, *Common Field and Enclosure in England, 1450-1850* (London: Macmillan, 1977), p. 150. Kerridge also develops an early chronology of field turnip husbandry in: Eric Kerridge, "Turnip Husbandry in High Suffolk," *The Economic History Review* 8, no. 3 (1956).
[9] "Turnip Husbandry in High Suffolk," p. 390.

as the root of modernity in the historiography of convertible husbandry and British economic growth. This is largely because historians like Harry Kitsikopoulos, Michael Moissey Postan, and Robert Allen have highlighted the important role played by turnips in increased nitrogen cycling via animal manuring. As convertible husbandry revised the boundaries between commons and arable, nitrogen fixing fodders combined with turnips were planted in the very acreage that would soon support wheat. New fodders allowed farmers to maintain larger acreages of meadow and grassland while increasing herd size per acre, and to exercise more control over the rotation of land between use types. Though period aggregate statistics represent gross estimates, Mark Overton argues that the acreage of meadow and pasture grew by about 47 percent over the eighteenth century compared to 38 percent for cropped acreage.[10] The opposite trend occurred during the early nineteenth century, which saw a 30 percent decline in pasture and a 47 percent rise in sown cropped lands.[11] As a back-bone of the British Agricultural Revolution, this simple rotation of manure thus marked the convertible design as a breakthrough for supporting continued crop cycles on arable that would otherwise transition through fallow or some period of woodland. Such studies prioritize the problem of nitrogen in the Medieval Period when grazing commons were likely saturated while arable suffered nitrogen depletion due to a lack of land use rotation. Earlier data are more difficult to piece together at the level of detail of total acreage, however due to England's position as a wool exporter beginning in the late Medieval Period, the trend towards pasture encroachment on arable is generally thought to have continued through the seventeenth century.[12]

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[10] Mark Overton, *Agricultural Revolution in England : The Transformation of the Agrarian Economy, 1500-1850*, Cambridge Studies in Historical Geography. (Cambridge ; New York: Cambridge University Press, 1996), p. 94.
[11] Ibid.
[12] Ibid.

Yet if we dig more deeply, it turns out that nearly early every economic contribution made by new fodders was contingent upon their combinations and with other species and soil improvements. Alternative fodders such as *B. napus* not only allowed convertible husbandry to be practiced at such a great scale that it transformed England's landscape, but also introduced manure into sandy and poor soils through convertible reclamation, thus improving humus structures, nutrient storage, and the soil microbiome. Though researchers have paid less attention to *B. napus*, much less the schematics used to integrate multiple feed and forage options into convertible husbandry designs, it is clear that turnips and the nitrogen fixing leguminous fodders were by no means the only contributors to this transformation which increased herd size and manure contributions. *B. napus* also increased animal inputs to improve soils and examples of *B. napus* as a stand-alone fodder and as a pairing with turnips and clover are also frequently documented by period writers though they have been less celebrated in the historiography.

To begin, in 1841 George Nicholls designed a full system of convertible husbandry in which *B. napus* fields grazed by sheep replaced the need for fallow during the preparation of permanent grass. He published his work in *The Farmer's Guide*:

> One great advantage which the culture of rape presents is the facility with which it can be produced on inferior soils on which a crop of rape may often obviate the necessity of an entire or naked fallow, for it may be eaten upon the ground by the sheep in the month of September.[13]

Here the importance of rapeseed integration into convertible husbandry is demonstrated by the use of the plant on poor soils in place of fallow. It might seem like a simple innovation—rather than allow soils to sit bare while they regenerate, farmers planted fodder during the fallow or unproductive seasons to integrate grazing and thus manure. But as this example shows, the

[13] George Nicholls, *The Farmer's Guide: Compiled for the Use of the Small Farmers and Cotter Tenantry of Ireland* (London: S.N.], Printed by A. Thom, 1841), Monograph, p. 109.

variability in soil quality limited the success of new fodder introduction. As we will soon show, *B. napus* helped overcome this constraint by thriving on soils where turnips struggled or were only marginally successful.

In addition to serving as fodder or feed to support crop diversification in convertible husbandry, *B. napus* meal was used as a manure for turnips and thus supported the expansion of a traditional fodder crop for convertible husbandry into a wider range of soils. In fact, one advantage of *B. napus* is that fodder would re-shoot after grazing and grow into a crop of oilseed. The meal remaining from the oil press was prized as a valuable green manure, in part because it helped farmers avoid the problem of mildew and plant disease. In the 1804 View of the Agriculture of the County of Norfolk, Arthur Young relayed the comments of a local farmer named Mr. Johnson:

> Rape cake is an excellent manure for turnips and does not subject them to mildew**;** they will grow longer than from any other manure. The turnip that grows most after Michaelmas is always of the best quality.[14]

Here *B. napus* increased the reliability of the turnip crop, which did not flourish in poor soils without manuring. This highlights the transcendence of the classic dilemma of the chicken-and-the egg; while the historiography has long focused on the importance of animal manures, the larger herd size needed to achieve soil improvement required farmers to have already cultivated better fodder crops. As a robust crop of turnips or clover similarly required manure inputs, forage crop innovation succeeded in part because herd sizes grew concomitantly. *B. napus* crops were similarly more successful after manuring, however as the plant survived on sandy, poor soils it could be planted as a first stage in improvement to extend animal grazing and thus

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[14]Arthur Young, *General View of the Agriculture of the County of Norfolk; with Observations on the Means of Its Improvement* (Cambridge, MA, United States: Kress Library of Business and Economics, Harvard University, 1813), Monograph, p. 419.

introduce manure inputs to new areas. As we will see in this chapter, the often neglected study of manure designs uncovers the mechanisms by which farmers overcame the tragedy of the grazing commons. Sites that could only support a few animals were able to sustain more fodder. Farmers thus expanded herd size and increased the manure inputs needed to support more regular plantings of fodder, more taxing fodders, and eventually more frequent rotations of cereals. As soils improved over time, crop yields also increased. *B. napus* cake left from the oil mill served as both an alternative to animal manure and as feed for livestock that might not have survived on fodder alone. This option was particularly important to farmers who manured turnips in environments vulnerable to soil disease.

This tactic even worked on larger-scale improvement practices. During a series of depositions on rapeseed called by the Select Committee on Seeds and Wool in May 1816, Mr. Joseph Howell of Caddington, Hertfordshire, described that many of the 5,000 acres he had converted to arable cultivation could only produce rapeseed during the first growing seasons. In response to questions about whether rape seed was essential to tillage in his country, Howell said:

> … the whole of this country is used as convertible husbandry: to go a little further, I calculate upon some part of this being fallowed for rapeseed; that being the case, my practice has been to use it as a kind of preparatory crop for wheat…”.[15]

While this quote lacks the spirited praise that Robson gave the turnip, it is clear that *B. napus* played an essential role in the conversion of the clay, flint, and chalk soils found in places like Caddington.[16] Howell estimated that about 50,000 acres total were planted in rapeseed each

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[15] Great Britain Parliament House of Commons Great Britain. Parliament. House of Commons, "Parliamentary Papers," *Parliamentary papers.* VI (1816), p. 35.

[16] “William Page, *The Victoria History of the County of Hertford*, 5 vols., vol. 2, Victoria County History (Westminster : London: Archibald Constable ; St Catherine Press, 1902), p. 187-93. “The soil is clay with flints, and the subsoil chalk, and the chief crops are wheat, barley, beans, and turnips,” https://www.british-history.ac.uk/vch/herts/vol2/pp187-193

year in Lincoln, Huntingdon, Cambridge, Norfolk and Sufolk.[17] Because the process of converting to arable was so expensive, Howell had only transitioned about 5,000 acres with 3,000 brought into cultivation at his own expense. Much of this drained land was not fit for wheat and could only be sown with rapeseed, though on better soils the wheat was sown directly into rape seed stumps.[18] "My practice has been to use [rapeseed] as a kind of preparatory crop for wheat, where the land is suitable for wheat," he wrote.[19] Drawing from rapeseed prices published in the same collection of testimony, Howell likely earned about 94,000 pounds a year from these efforts, showing that rape seed farming was a lucrative business. This is based on his account of 20,000 quarters per year in harvests as well as other accounts in the testimony that farmers earned 47 pounds per ten quarters of rape seed.[20]

B. napus thus expanded the ratio of planted acreage by performing on poor soils otherwise capable of supporting only light grazing. As we will explore in this chapter, the expansion of net productivity through the enclosure of waste, moor, and unproductive grazing commons was made possible in part by the performance of *B. napus* on water logged, sandy, and depleted soils. It is important that farmers like Howell acknowledge rapeseed as a component of this larger model of land use efficiency.

The powerful contributions made by *B. napus* to convertible husbandry on poor soils were also described by Samuel Smith in the Farmers' Cabinet in 1839. Smith wrote:

> There have been, says he, instances, on cold, unproductive old pasturelands in which the produce of the rape crop has been equal to the purchase price of the land. The leaves as green food for sheep are not surpassed by any other vegetable in nutritious qualities.[21]

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[17] Great Britain. Parliament. House of Commons, "Parliamentary Papers," p. 35.
[18] Ibid., p. 36.
[19] Ibid., p. 35.
[20] Ibid., p. 36, 40.
[21] Samuel Smith, "Cultivation of Rape," *The Farmers' cabinet* 3 (1839), p. 221.

While this may first appear to be a conversion of pasture to pasture, the quote actually describes the conversion of unproductive, over-grazed pasture to planted fodder. The period actor described the land use type change. Smith next noted the importance of growing *B. napus* for oil seed, which also contributed to the value of unproductive pasture. A single planting potentially doubled for grazing and oil crop. It was this type of integration into the same system that increased design efficiency. Here lies the most important contribution of *B. napus*—it was highly malleable as a design tool and formed an integrated, closed-loop system by turning waste into a product. As we will see, the case study of rapeseed depicts the integration of waste into the productive cycle as lands with almost no other value could be planted and grazed. The additional crop of oil seed also contributed crushed meal, thus allowing farmers to harness an industrial waste product as a manure input to increase soil fecundity. In addition, the larger herd sizes supported by *B. napus* fodders as well as the turnips manured by *B. napus* meal both increased land value for generations in terms of livestock productivity and increased grain yields. Alternatively, the farmers who faced the problem of unproductive pasture would have needed to pay large sums to import soil amendments like guano, or they would have needed to cart manures from far off site.

The next section explores the numerous examples of *B. napus* use for winter fodder and feed in convertible husbandry designs. Later, we uncover *B. napus* and turnip combinations that supported transitions from bare to green fallowing. By harnessing this defining technique of convertible husbandry, farmers knowingly integrated *B. napus* to reduce bare fallows and grazing on permanent pasture by shifting animals to planted fallows that once sat bare. We will conclude by exploring the spatial scale of eighteenth-century convertible designs in order to understand the limits of common field and grazing organization. *B. napus* was also uniquely suited to expand agriculture into moor and marsh, often by serving as one of the first plantings during the conversion of these landscapes to grazing and arable. However it also gave farmers the option to more rapidly transition larger spans of arable through a grazing cycle and to increase the carrying capacity of grazing fields through planted meadow designs. No longer did the carrying capacity of a natural meadow most often managed in common determine herd size. While this was not an infinite growth spiral, farmers increased cycles of feed and fodder production until their herds were large enough to provide meat and dairy for the table and

Table 3.1 *Brassica Napus* (Rapeseed) Substitution Pre-dates Turnips

Turnips

1640s:	Eric Kerridge counters the story of Turnip Townshend's early-eighteenth century introduction of turnips for fodder by showing field turnip cultivation for milk cows in High Suffolk in the mid-seventeenth century. The above-ground portion of the turnip plant substitutes common pasture. The white turnip bulbs serve as winter feed.

B. Napus:

1542 to 1549:	Prices of Spanish olive oil for textile finishing grew by a third.
1551:	First rapeseed project located at King's Lynn to supply St. Radegund's priory.
1553:	Spain began to require a license for selling alum abroad, sparking fear that restrictions might soon follow suit for olive oil.
1565:	Patent in England covering the production of oil from seeds.
1570:	Olive oil supplies jeopardized due to political tensions with Spain.
1571:	Another device for making oils for English clothiers was developed.
1572:	A parliamentary bill was introduced to spur the making of oils in England. A cluster of patents followed.
1570s:	Spain was now selling olive oil to colonies in the West Indies and threatened long-term shortages in Europe that would prevent shipments to England.
1579:	Growers in King's Lynn alone were shipping 2,000 quarters of rapeseed a year.
1624:	King James I Edict granted clothier Benedict Webb monopoly rights to import a French model for rape oil production for textile finishing. Edict lists soil improvement benefits and the goal to offset trade dependency on precarious supplies of Spanish olive oil.

Source: Joan Thirsk *Alternative agriculture: a history from the Black Death to the present day.* (New York: Oxford University Press, 1997).[22]

[22] Joan Thirsk, *Alternative Agriculture: A History from the Black Death to the Present Day* (Oxford: New York : Oxford University Press, 1997).

livestock for the market. By so doing, grain yields continued to increase and the land supported more cycles of cash crops of raw materials for industry and food for a growing population. Nitrogen fixers alone were not enough to facilitate the more complex rotation designs that integrated winter feed production in the form of grass and root crop plantings. *B. napus* also provided dried stalk for winter feed and the potential to cycle crushed cakes and meals through the feed cycle as well as through the manure process. Even if the benefits of pathogen suppression and phosphate release were marginal, the story of rapeseed as a fodder facilitates a revision of the soil improvement narrative to re-evaluate the importance of design innovation. As the rate of conversion as well as the total percent distribution of land use types was modified by farmers, the reciprocal codetermination between fodder innovation and larger herds manifested in the demands of turnips for manure. *B. napus* helped meet this need, thus opening a wider range of soils to field turnip agriculture.

"What, indeed, has not turnip husbandry done for England?," asked Robson. "Why, practically, it has doubled our acreage and doubled the duration of our summer... Turnips have made us for a very great part of the year independent of grass, and have enabled us to go on feeding the whole year round…"[23] This quote illustrates a late nineteenth century actor's understanding of the environmental function of turnips as a fodder; by reducing dependency on grass, extending the feeding season, and increasing the acreage used for grazing, turnips allowed both animals and humans to be well fed the full year round. Yet as we will next see, it was *B. napus* combined with turnips that helped herds survive the bitter winters. Though *B. napus* was not the only fodder or feed available to serve as winter food, it may have been among the most frost resilient option for late fall and early spring plantings.

[23] Robson, "Turnip Husbandry," p. 101-2.

II. Rapeseed for Winter Feed

Convertible husbandry is most often defined as the rotation between permanent, self-sustaining grassland and arable, but it was also described by period actors as a mechanism for expanding mixed husbandry functions that allowed farmers to grow feed, fodder, and crops as part of managed grasslands or in rotations between arable and planted grass. By the late eighteenth century, farmers were widely publishing their strategies, and rapeseed was one of the tools used to facilitate this advancement. *B. napus* grown in series was fed to animals as green fodder planted in the field, as winter hay prepared as dried stalk, or as cake crushed at the oil mill. Evidence shows this made convertible husbandry possible in marshy lands and poor soils where turnips were less successful. To begin with a few examples, in 1789 James Adam described in *Practical Essays in Agriculture* that *B. napus* both sustained animals through the winter but also fattened them better than turnips in advance of the cold months. He wrote:

> Some farmers sow rape feed merely for the sake of the winter feed it affords the cattle. It is the most fattening of any for sheep. They will thrive more on rape feed plants in one month than on turnips in two if put in soon after Michaelmas. In this case when the crop is fed off… there is always a good crop of barley after it...[24]

rapeseed served not only as a food for sheep but also as a soil improvement to prepare soils for barley. By illustrating that rape was planted in the late fall after Michaelmas, we see the potential for the plant to not only survive cold weather but germinate and grow through the seedling stage during a time of the year when other crops had passed harvest and were beginning to wane.

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[24] James Adam, *Practical Essays on Agriculture : Containing an Account of Soils, and the Manner of Correcting Them. An Account of the Culture of All Field Plants . Also, an Account of the Culture and Management of Grass-Lands; Together with Observations on Enclosures, Fences, Farms, and Farmhouses, &C. Carefully Collected and Digested from the Most Eminent Authors, with Experimental Remarks*, 7 vols., vol. 1 (United States, North America: London : Printed for T. Cadell, 1789), p. 509.

From Wiltshire to the Scottish Highlands, rapeseed similarly doubled as winter feed and soil improvement. According to the 1794 *General View of the agriculture of the county of Wilts:*

> RAPE or Cole seed is much cultivated on the downs particularly on those parts that are peculiarly unkindly for barley and turnips… It is certainly when under proper management a most valuable green winter food and particularly as it will grow in those kinds of soil in this district where neither turnips, saintfoin, vetches, clover and in some instances not even ray grass will grow viz the strongs cold wood four land and the black loose soil of the downs.[25]

Here rapeseed is preferred as winter feed above not only turnips but the nitrogen fixers like clover and sainfoin, which struggled in the cold and on poor soils. The downs were unfit for even ray grass and had little other purpose until rapeseed was introduced for winter forage. *B. napus* facilitated the conversion from waste to grazing and thus made the land productive. The passage continues by praising rape for offering great advantages beyond estimate to the Kingdom of England. "Yet this may be laid down as a certain maxim that whether the winter be hard or mild, whether the spring be late or early, nature will always have in this climate an interregnum between the end of one year's food and the beginning of another," wrote Thomas Davis.[26] Though Davis complained that rape exhausted the land unless fed off early before taking a deep root, the crop was thought very nutritious for ewes that had lambs.

Mr. Marshall similarly developed designs that incorporated winter feeds. In the *General View of the Agriculture of the Central Highlands of Scotland* he wrote that the "backwardness of spring" could be counter acted with modern husbandry such as turnips and rapes.

> By turnips, rape, cabbages, and potatoes, the severities of winter and the backwardness of spring would be equally guarded against as the lateness of harvest might by keeping the land in a high state of cultivation…"[27]

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[25] Thomas Davis *General View of the Agriculture of the County of Wilts. With Observations on the Means of Its Improvement. Drawn up for the Consideration of the Board of Agriculture and Internal Improvement, by Thomas Davis, of Longleat, Wilts, Steward to the Most Noble the Marquess of Bath* (London: [s.n.], 1794), p. 50.
[26] Ibid., p. 103.
[27] William Marshall, *General View of the Agriculture of the Central Highlands of Scotland; with Observations on the Means of Their Improvement*, ed. Agriculture Great Britain. Board of and Mr Marshall (London: Printed by T. Wright, 1794), p. 53.

In this case study, rape functioned as more than a mere crop diversification strategy to supplement turnips. It was a central element around which complex design schematics were creatively configured so that farmers could extend the seasonal temporality of plantings. In fact, sheep were fed through the entire winter with rapeseed in the northerly Perth. In the 1799, James Robertson reports that the seasonal performance of rapeseed worked to supplement turnip grazing during the critical coldest months. According to Robertson, "The ground is prepared for rape or cole seed in the same manner as for a crop of turnips, and both are sown about the same time. The rape is so hardy as not to be destroyed by frost and therefore is of great service in hard winters for feeding sheep."[28] As rapeseed grew longer into the winter, it provided the farmer with a reliable food source that complimented the growing cycle of the turnip. This was especially helpful for farmers who housed their own cattle. Hay and straw were more nutritious and lasted longer when mixed with rape, rapeseed cake, or the tops of turnips and rutabaga.

To understand these planting designs as a form of convertible husbandry, we must explore the importance of winter feed to herd size and the role of long-term manure inputs in England's escape from the tragedy of the grazing commons. In 1841, as he returned to Britain from travels in the USA and Canada, Captain Barclay described that prior to the introduction of convertible husbandry in Scotland, it was common to see livestock reduced to near starvation by the end of winter. In 1842 Barclay described that many animals were barely able to walk to the pastures in the Spring:

> … for at a period not yet beyond memory, before the introduction of convertible husbandry in Scotland, it was nothing uncommon to see the farmer's stock so attenuated by the dearth and insufficiency of winter food, as to be almost unable to walk to their pastures in spring. But with *convertible husbandry* came the cultivation of turnips, and

[28] James Robertson, *General View of the Agriculture in the Southern Districts of the County of Perth with Observations on the Means of Their Improvement*, ed. Board of Agriculture (London: Printed by J. Nichols, 1794), p. 187.

> other green crops before unknown. By the use of such green crops, the straw came to be converted into valuable manure; the soil was rendered greatly more productive; and now, at the end of winter, the stock of a Scotch farmer is not the mere skin and bone of former times, but in the best condition; or, if such has been the purpose, ready for the butcher.[29]

Modern historians like C. Peter Timmer similarly described how the turnip, when meticulously hoed as recommended by the best agricultural authorities, cleaned the fields of weeds and supplied winter fodder for the larger herds.[30] He wrote that "livestock huddled together on the weed-overrun commons, were thinned before winter because of insufficient winter feed."[31] However the system of convertible husbandry in its slow and steady emergence solved both the problem of winter feed while improving manure loads. In fact, Timmer claims that the accelerating growth of convertible husbandry in the latter half of the eighteenth century was made possible by the introduction of a new fodder supply in the form of turnips. Alternatively, Jeanette M. Neeson describes how prior to a feasible convertible husbandry system, many farmers could only prevent the winter slaughter of their livestock by selling sheep to neighbors with more land. Only if they had money after the cold season could they buy the herd back in the spring. This model worked because the neighbor with the greater food supply also benefitted greatly from the extra manure. In contrast, farmers who relied upon some combination of grazing common rights, leased pastures, or limited mixed husbandry were forced to reduced herd sizes in late fall and early winter to ensure there was enough feed for the remaining animals through the cold season.

While rapeseed was not the only innovation important to herd survival, the application of the crop as winter feed is an indication that turnip-centered narratives like the one developed by

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[29] Captain Barclay, *Agricultural Tour in the United States and Upper Canada with Miscellaneous Notices* (Edinburgh: W. Blackwood, 1842), p. 144.
[30] Timmer, "The Turnip, the New Husbandry, and the English Agricultural Revolution," p. 383.
[31] Ibid., p. 377.

Timmer neglect the diversity in fodder innovation. For example, in Cornwall, George B. Worgan lamented the loss of dung during the winter due to shortages of green crops. In his 1815 *General View of the Agriculture of the County of Cornwall* he writes:

> ….from the general deficiency of houseroom and comfortable farm yards throughout the county as also of more extensive winter green crops, all cattle particularly young stock sustain much injury for want of more generous food… but the evil by no means stops here, for not one quarter of the dung is raised that might be, and a long train of evils followed from this deficiency.[32]

To resolve this deficiency, "Gentlemen and some superior farmers house all their cattle giving their cows cabbage, rape, or the tops of turnips and ruta baga with straw or hay."[33]

Until the second half of the eighteenth century, the sight of a large herd of cows grazing in the village commons—the iconic example of land degradation in *Tragedy of the Commons* by Garrett Hardin—would have been a rare sight in many communities in England.[34] While England surpassed France and may other Western European nations by producing more livestock per acre and by total quantity by the end of the eighteenth century, the kingdom entered the early modern period with fewer wagons, less travel by horseback, and fewer animals. As a maritime kingdom, England expanded canals and coastal shipping routes before developing the complex systems of roadways used for land-based trade in continental Europe. Carriages and horse-drawn wagons were not as common as canal boats. Advances in animal breeding and livestock management were made possible in part by agricultural improvements that allowed the landscape to support more animals.[35] The herd size on the commons expanded only as more land was converted to pasture, and due to fines and land covenants, it would have been difficult for the

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[32] George B. Worgan, *General View of the Agriculture of the County of Cornwall*, ed. Agriculture Board of and George B. Worgan (London : (London: Sherwood, Neely & Jones, B. MM̀illan), 1815), p. 147.
[33] Ibid.
[34] Hardin Garrett, "The Tragedy of the Commons," *Science* 162, no. 3859 (1968), p. 1244.
[35] E. A. Wrigley, *Continuity, Chance and Change : The Character of the Industrial Revolution in England* (Cambridge England ; New York: Cambridge University Press, 1988), p. 7, 14-7.

tragedy of the commons to unfold as Hardin described—as each herdsman realized that the effects of overgrazing were shared by all and "the only sensible course for him to pursue [was] to add another animal to his herd. And another; and another…"[36] For the early modern and eighteenth-century farmers, the ability to breed cows in the spring and increase herd size over time raised questions of fodder and grass regeneration as much as issues of grazing rights or fines for additional animals.

In his famous article, Hardin references Adam Smith when developing his premise of the prisoner's dilemma. Rightfully so, as when applied to the problem of environmental resources, this model of scarcity is illustrated in terms of the law of diminishing returns. Two actors choose selfishly to over-graze even when cooperation might support regeneration of the pasture. However as E. A. Wrigley described, the increased production of livestock, raw material, or natural resources was regulated by resource scarcity. In land-based economies that lack fossil fuel inputs, growth limits the future growth potential of markets that compete for resources. Unless growth occurs at the rate of regeneration, future growth is limited in the same and competing markets.[37] If we apply this model to seventeenth and eighteenth-century livestock, we see that husbandry was difficult from the perspective of environmental design because the expansion of herd size risked this law of diminishing returns. As the herd size grew, pasture expansion cut into arable or woodland resources. Increased manure initially supported more robust pasture and better soils as sections of pasture could be transitioned to arable during long-term rotations. This initially increased the fat and protein in the human diet and supported population growth. Yet as the herd size grew, the burden of a hard winter or an early frost required that more arable be dedicated to feed production, and this eventually cut into food

[36] Garrett, "The Tragedy of the Commons," p. 1244.
[37] Ibid., p. 3-6, 12, 17, 18-21, 24-5, 29-30, 34-5.

production for the growing human population. Conversely, if the herd was too small, there was not enough manure input to regenerate the pasture. In this case the pasture would deteriorate so that it could not support a large herd in the future without improvement. Over-grazing was the tip of the iceberg when it came to environmental limits. Some villages could not even collectively pull together enough cows and sheep in the commons due to the lack of winter fodder and feed. Over-grazing was just one concern.

As we have seen, rapeseed played an important role in convertible designs because it increased the winter carrying capacity of the land as both a fodder and storable feed. In Perth, James Robertson described a synchronistic design that timed the planting and grazing of rape and turnip crops to increase the seasonal availability of fodder through colder seasons. It turns out that rapeseed was cut much like hay for dry feed. "When turnips are locked into the ground by the frost, the rape may be cut off for a supply, and the stems shooting up again early in the spring will produce a second crop**…,"** wrote Robertson.[38] He indicates that the second crop of rapeseed could be eaten green by livestock in the spring in times of food scarcity. If other feed was available, the rape would be left to run to seed to be "sold in advantage and bruised for extracting the oil."[39] In the 1794 edition of this same work, rapeseed is listed under "GREEN CROPS," a category defined by the plant's ability to fertilize and cleanse the land and to provide more healthy winter feed by affording a change in diet. This points to a greater complexity of design than is often considered in the historiography of introduction and dispersal. To the contrary, the ability to integrate a new species into an agricultural and economic system required innovative environmental designs. Whether discovered by accident or through trial and error, it is no small

[38] Robertson, *General View of the Agriculture in the Southern Districts of the County of Perth with Observations on the Means of Their Improvement*, p. 188.
[39] Ibid.

detail that a single planting of *B. napus* offered both fodder, dried hay, and a second crop of valuable oilseed and thus cake for feed or green manuring.

Returning to Baldwin and *The Complete Farmer; or General Dictionary of Agriculture and Husbandry,* we learn that "cole, or rape" was similarly "cultivated as a spring-food for sheep." Baldwin explained how sheep were "folded in the same manner as on rye and turnips, and continue[d] till about the end of February."[40] Baldwin even allowed the cole planted for grazing to stand for seed if the winter was favorable, and not very wet. This produced as much as thirty bushels, on an average, per acre. Later in the same work he confirmed this practice a second time when he wrote "And, by means of the same expeditious method of cutting up stubbles… on cole, or rape, or turnip, for food or sheep or cattle in winter or spring, extraordinary advantages may be derived."[41] As we will see in the next example, the multiple functions offered by rapeseed as winter feed illustrates the plants adaptability to complex agricultural systems that varied between farms and geographies. In contrast, *B. rapa subsp. rapa* could be planted in only two ways; it could be grown for fodder or left to form a bulb underground.

To better understand convertible husbandry mechanisms, other period examples describe the use of planted fodder in place of permanent pasture for winter feed. Planting details that illustrate the combining of turnips with rapeseed for the purpose of increasing winter feed stock. In 1794, Thomas Stone wrote that:

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[40] Baldwin, *The Complete Farmer; or, General Dictionary of Agriculture and Husbandry: Comprehending the Most Improved Methods of Cultivation; the Different Modes of Raising Timber, Fruit, and Other Trees; and the Modern Management of Live-Stock: With Descriptions of the Most Improved Implements, Machinery, and Farm-Buildings.*, i, p. 440.
[41] Ibid., p. 974.

> the proper fallowing, cultivating, and hoeing [of] turnips or other green winter food for cattle and sheep such as cole or rape… are objećts in the pursuit of which the majority of the Bedfordshire farmers are near a century behind Norfolk and Suffolk.[42]

In Essex in 1794 Messrs**.** Griggs wrote that "rape or cole" were "also cultivated as winter and spring food for sheep" and that "rape seed [was] frequently sown among turnips or alone to be fed off."[43] That same year Charles Vancouver reported that cole and turnips were sown in Cambridge for the feeding of sheep in the winter.[44] The second edition of the *General View of the Agriculture of the County of Cambridge* was penned by William Gooch in 1811 and shows that this practice continued at least through the first part of the nineteenth century. Gooch advised sowing cole with ray grass and hay seeds for winter feed[45]. He also recommended the practices of the fen farmers. He wrote "some of them sow[ed] a quarter or a half a pound of turnip seed with the half peck of cole-seed on an acre….". The crops "answered well" when grown together, preventing the problem of crop failure. According to Gooch, when the cole-seed was a fair average crop, an acre fed "eight large Lincolnshire sheep, or a greater number of the smaller sorts."[46]

It is important that this last example explicitly describes rape sown on the same acre with turnips to feed sheep, as this illustrates the integration of polyculture into an agropastoral design. Polyculture involved the growing of more than one species at the same time and place to

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[42] Thomas Stone, *General View of the Agriculture of the County of Bedford: With Observations on the Means of Improvement*, ed. Agriculture Board of and Thomas d Stone (London: Printed by E. Hodson, Bell-Yard, Temple-Bar, 1794), p. 22.
[43] Griggs Messrs, *General View of the Agriculture of the County of Essex with Observations on the Means of Its Improvement*, ed. Board of Agriculture (London: Printed by C. Clarke, 1794), p. 16, 26.
[44] Charles Vancouver, *General View of the Agriculture in the County of Cambridge: With Observations on the Means of Its Improvement. Drawn up for the Consideration of the Board of Agriculture and Internal Improvement.*, ed. Board of Agriculture (London: Printed by W. Smith, 1794), p. 122, 42.
[45] William Gooch, *General View of the Agriculture of the County of Cambridge*, ed. Agriculture Board of, Goldsmiths'-Kress Library of Economic Literature ; (London: Printed for Sherwood, Neely, and Jones, 1813), p. 105, 14.
[46] Ibid., p. 114.

diminish pest infestations, which spread less rapidly in a mixture of plants when one species offers a less favorable breeding and feeding habitat. The integration of rape into mixtures of fodders for convertible designs was highly innovative in the mid-to-late eighteenth century. John Aikin described in *A description of the country from thirty to forty miles round Manchester* how Mr. Eccleston mixed rapeseed with grass to facilitate grazing on lands flooded during the 1789 late autumn and early winter floods. When the banks of the river Douglas flooded along with the Leeds and Liverpool canal, thus inundating the drained lands of the Meer, Eccleston turned to grazing rather than tillage. "He found grass-seeds and rape mixed, a very useful crop in keeping his lambs; and flax succeeded well, being fit to pull earlier than any danger can raise from the autumnal floods," wrote Aikin.[47]

To plant rape in mixture with turnips, rye or grass, farmers would have needed to understand the seasonality of planting, spacing, and germination of each crop as well as their interactions during the growth cycle to ensure that they matured at the right time for grazing under different environmental constraints. As we learn from Gooch, this design was strategically developed to offset the losses of crop failure so that when turnips came up sparse, the coleseed would provide. William Ellis confirmed this same strategy in *The Modern Husbandman* when he wrote "…by sowing so many seeds together, a Man stands a much surer chance of a crop."[48] Ellis described the planting of cole or rape mixed with turnips and weldseed between rows of apple and pear trees for the feeding of sheep or "milch-cows." This strategy of tri-planting was

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[47] John Aikin, *A Description of the Country from Thirty to Forty Miles Round Manchester: Containing Its Geography, Natural and Civil; Principal Productions; River and Canal Navigations; a Particular Account of Its Towns and Chief Villages; Their History, Population, Commerce, and Manufactures; Buildings, Government, &C*, ed. John Stockdale (London: Printed for John Stockdale, 1795), p. 325.
[48] William Ellis, *The Modern Husbandman, or, the Practice of Farming. Containing, the Months of October, November, and December.*, v. 4 vols., vol. v. 4 (London: Printed for, and sold by T. Osborne, and M. Cooper, 1744), p. 48.

particularly useful for the gravel, gravel loams, and sandy soils often planted with orchard trees because wheat and other cash crops performed poorly. [49]

Due to the diversity of growing environments in which rapeseed succeeded, the literature is replete with stories of farmers discovering and re-discovering the many agronomical functions offered by the plant. A unique story about an English farmer in America suggests that the crop's capacity to work in a multi-functional temporal design was so surprising that it was shared through news headlines. An article published in *Plough-Boy* outlined the innovation process for American readers. In Salem, New Jersey, an anonymous Englishman produced forty bushels of rape seed on two acres after the fodder was grazed and re-grew to seed. The story was relayed by the miller. He humorously describes that the crop was originally intended for seed until mischievous cattle broke into the field and destroyed the rapeseed by foraging. The farmer gave up and let the heard roam in the rape field all winter. In the spring, the miracle of an abundant seed crop was a surprise to all. According to the miller:

> …but in the spring, observing [the rape] sprouting again, [the English farmer] put up the fence, and as he expressed himself, "let it take its chance." The two acres, with this, as he considered it, unfair experiment, produced him about forty-four bushels of seed, for which I offered him four dollars per bushel… I produced three and a half gallons of oil per bushel.[50]

Here the miller completes the cycle of nutrients on the farm by introducing the fourth *B. napus* function. Not only did a healthy second crop of rapeseed provide a lucrative supply of oil even after successfully tempting the farmer's cattle with fodder, but the crushed seed cake was returned to the farm as a feed. The farmer sold a portion of the seed to pay for the milling, but made a profit off the oil produced in the making of his prized cake. The miller wrote:

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[49] Ibid., p. 46-8. In this same section of work, Ellis also wrote "For if the rapes miss, the Turneps and Weld may hit, or if both Rapes and Turneps miss, the Crop of Weld, if it is a good one, will pay all Charge and Trouble…".
[50] Anonymous, "Culture of Rapeseed for Oil," *Plough-Boy: Devoted to Agriculture, Hortculture, Manufactures, Literature, Science, News & Miscellany* 3, no. 16 (1834), p. 134.

> The cake, that is, the pulp, after the oil is expressed from it, he valued highly for fattening cattle… the oil he sold to a woolen manufacturer for one dollar and thirty cents per gallon, thus, including the cake, realizing five dollars and thirty cents per bushel, out of which he paid the expense of manufacturing.[51]

The miller never heard of the farmer again and wondered if he perhaps returned to England, yet from this transaction the miller determined that rapeseed would also succeed in America as it did in England due to the plant's adaptability. According to the miller, "if it will not succeed in one district, it certainly will in some other."[52] While the cattle are perhaps to thank for having broken into a field and eaten a cash crop planted for oilseed, this mischief combined with the farmer's neglect gave rise to a complex design schematic. In the end, every part of the *B. napus* plant from the stalk to the seed and crushed cake was exploited by the farmer for gain.

B. napus cake was easily stored through the winter and could be used for feed during the cold, dark months when pastures stopped growing. This phase of the production cycle can be clearly reconstructed from period accounts. Just as turnips were planted for white bulbs to store in a shed to feed the herd, rapeseed offered cake in addition to dried stalks to supplement the diets of hungry livestock during the winter. In a 1768 issue of the *Gentleman's & London Magazine.* We see the rape cakes from the press used *"*for fattening the greatest number of cattle with rape seed, from which the oil has been pressed out…".[53] This same issue published premium structures paid by the Dublin Society to encourage rape mills and the planting of more than 10 or 15 acres. Returning to England and the *Practical Essays on Agriculture*, James Adam similarly wrote "I have already mentioned the cakes of the rape or cole seed as excellent manure for land but they are now so much used for the food of cattle that they are become a very

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[51] Ibid.
[52] Ibid.
[53] "Husbandry," *Gentleman's & London Magazine; or Monthly Chronologer* (1768), p. 584.

expensive dressing."[54] In 1796, the Board of Agriculture published a report in its appendix of farming technologies. Rape was listed under "Oil Cake" and the manual describes that after pressing oil during manufacture, "these cakes still retain a portion of oil and highly concentrated mucilage, and are therefore usefully applied to the feeding of cattle. They are also frequently [used] as manure."[55] J. H. Powel preferred rapeseed cake for feed above the greens, which sometimes bloated animals. In an 1828 edition of the *New England Farmer* he published an article titled "On Rape—its cultivation and produce in Seed—Its value as Green Food for Neat Cattle and Sheep." He wrote:

> I believe, that [rape] quite equals the common cabbage, and very far exceeds turnips of all kinds in the quantity of nutrition it contains—in the value of the oil for various manufacturing purposes, and the excellence of the cake, after it has been expressed, for cattle food and the manure of drill crops, no question can be entertained.[56]

By providing food for the over-wintering of animals, convertible strategies supported the emergence of a more modern farm. Eventually, animals could be kept indoors during the winter and individual family farms became less dependent upon commons.

Today the barn or "cowhouse" is something that every child outlines in red on their drawing of the farm, yet this structural innovation remained controversial as a design element in England as late as the eighteenth and early nineteenth centuries for the difficulty of producing a winter supply of feed that could be stored dry for indoor feeding. As an environmental design, stall feeding was beneficial because it gave farmers the option to entirely remove animals from

[54] Adam, *Practical Essays on Agriculture : Containing an Account of Soils, and the Manner of Correcting Them. An Account of the Culture of All Field Plants . Also, an Account of the Culture and Management of Grass-Lands; Together with Observations on Enclosures, Fences, Farms, and Farmhouses, &C. Carefully Collected and Digested from the Most Eminent Authors, with Experimental Remarks*, p. 520.
[55] Board of Agriculture, *Additional Appendix to the Outlines of the Ffteenth Chapter of the Proposed General Report from the Board of Agriculture. On the Subject of Manures.*, ed. Agriculture Board of (London: Printed by W. Bulmer and Co., 1796), p. 32-3.
[56] John Hare Powel, "On Rape--Its Cultivation and Produce in Seed--Its Value as Green Food for Neat Cattle and Sheep. Powelton, Philadelphia Country, 1827," *New England Farmer* 6, no. 35 (1828), p. 277.

the field while continuing to collect manure. Animals could be allowed to forage in green fallow when fodder ripened and then penned during months when planted fallows or grasses were regenerating. Here the more modern practice of turnip and rape fallowing supported the longer periods of indoor feeding, and pasture runs became more widely enclosed for fodder plantings. In the case of *B. napus*, grazing could be timed to facilitate reshooting for oilseed production without jeopardizing fodder supplies.

Such designs also reflect the movement away from a landscape of common grazing rights and permanent arable assignments to the privatized farm. As a vehicle of convertible husbandry that supported more innovative and site-specific designs, crops like rapeseed were thus instrumental in the development of this option. In fact, in the 1813 *General View of the Agriculture of Middlesex* John Middleton discouraged common field designs for preventing the integration of coleseed during winter rotations, which in turn prevented the cycling of manure into the agricultural system. He advocated for the move to the more diversified and productive landscape of convertible husbandry when he wrote:

> …a perfect system of husbandry is not possible in common fields, from the circumstance of the almost total exclusion of winter tares, cole, turnips, and clover. Where the rotation of crops is very imperfect in any part of this county, it is evidently to be attributed to the arable fields being in common… But anything short of the enclosure of all common arable land, should not be listened to, not even for a moment.[57]

Of course enclosure is not synonymous with convertible husbandry. But the integration of winter feeds like coleseed and turnips was a major asset during the enclosure process, as this also supported increased manuring from herds supported by winter greens.

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[57] John Middleton, *General View of the Agriculture of Middlesex : With Observations on the Means of Its Improvement, and Several Essays on Agriculture in General. Drawn up for the Consideration of the Board of Agriculture and Internal Improvement*, ed. Agriculture Board of and John land surveyor Middleton, 2nd ed. ed. (London : sold by G. and W. Nicol: Printed for Sherwood, Neely, and Jones, 1813), p. 191.

The ability to support new winter feed introduction in convertible husbandry marks a period transition, though the chronology of this transition remains debatable. In the 1936 *English Farming Past and Present*, the renowned Lord Ernle referenced convertible husbandry as part of a solution that harnessed winter feed to increase manure inputs. He described open-field farms, which "commanded little or no manure for their arable land" and reduced animals to "the lowest possible number" in winter, when livestock "barely survived on straw and tree-loppings."[58] He extended this problem to the Middle Ages when he wrote:

> …there was little to mitigate, either for men or beasts, the horrors of winter scarcity… On land which was inadequately manured, and on which neither field-turnips nor clovers were known till centuries later, there could be no middle course between the exhaustion of continuous cropping and the rest-cure of barrenness.[59]

The Tudors overcame the environmental limits of winter scarcity through the integration of new fodders into convertible husbandry. They improved the problem when they learned that a small enclosed plot of 15 acres could be used with less advantage than a large enclosure of 150 acres. This "enabled the tenant to invest money in the land, carry more stock, provide his cattle with more winter food, and if the climate permitted, adopt convertible husbandry," wrote Ernle.[60] He only briefly mentions rape and cole as experimental crops pressed upon the attention of farmers by the agricultural writers.[61] In Cleves, Ernle suggests that rape was valuable "for green-manuring, for the oil in its seeds, or for use as fodder for sheep."[62] Yet it is clear from period

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[58] Rowland E. Prothero, Baron Ernle, *English Farming, Past and Present* (London, New York: Longmans, Green, 1912), p. 65.
[59] Ibid., p. 33.
[60] Ibid., p. 64.
[61] Ibid., p. 108.
[62] Ibid., p. 100.

sources that by the second half of the eighteenth century, rapeseed was used in much the same way as turnips by farmers perfecting winter feed sources.[63]

In 1841 George Nicholls wrote in *The Farmer's Guide: Compiled for the Use of the Small Farmers and Cotter Tenantry of Ireland* that rape possessed such a hardiness of constitution that "as a green crop for winter or spring feeding it [was] invaluable yielding an abundant supply of nutritious food at a season when turnips and mangel wurzel [were] usually exhausted…."[64] Similarly, in Dumfries, a farmer wrote in 1812 "I would sow rape in preference to sowing turnips very late in the season… rape frequently turns out to good account by being eaten on the ground by sheep. It is considered the most nourishing green food that is given to sheep... I have no doubt of rape in many cases being a good substitute for turnips though I have not tried the experiment accurately.[65] In keeping with the interests of scientific agriculture, John Marius Wilson wrote that "Any land which has been cropped with winter rape and fed off in winter or in spring with sheep provided due culture has been given and no extraordinary wetness of weather have prevailed is in a state of very high amelioration."[66] For example, in the 1849 *Rural Cyclopedia: Or a General Dictionary of Agriculture*, Wilson attributed the gains in

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[63] In *The Agricultural Revolution*, Kerridge similarly defined convertible husbandry according to the more efficient utilization of manure due to the periodic alternation of grazing and tilling within the same field. Better winter feeds thus resolved the centuries-old stagnation of nutrients that had become over-saturated with manure while enriching arable acres depleted of nutrients due to continuous planting over time. Both Ernle and Kerridge contrasted these Medieval problems to the more innovative Tudor projects and traced convertible husbandry to the late sixteenth century. Kerridge, *The Agricultural Revolution*, p. 200-07.
[64] Nicholls, *The Farmer's Guide: Compiled for the Use of the Small Farmers and Cotter Tenantry of Ireland*, p. 109. Nicholls also argued that that rape was beneficial for having a wider range of soils than the turnip, for requiring less culture and less manure than the turnip, and for being produced where the turnip cannot be profitably cultivated.
[65] William Singer, *General View of the Agriculture, State of Property, and Improvements, in the County of Dumfries*, ed. Agriculture Board of and Dr Singer (Edinburgh: J. Ballantyne and co.; [etc., etc.], 1812), p. 579.
[66] John M. Wilson, *The Rural Cyclopedia, or a General Dictionary of Agriculture : And of the Arts, Sciences, Instruments, and Practice, Necessary to the Farmer, Stockfarmer, Gardener, Forester, Landsteward, Farrier, &C*, ed. John M. Wilson, 4 vols., vol. 4 (Edinburgh; London: A. Fullarton, 1849), p. 19.

productivity following rape grazing to the fixation of atmospheric gases via the deposition of animal excrements.[67]

Merely rotating natural, self-sustaining grass and cycles of arable through the same acreage did little to expand herd size unless the crop land could produce winter feed all while sustaining or increasing food production for human populations. We can trace the environmental impact of winter feed from the late eighteenth century. It is possible that Brassica was used earlier in this manner, but we lack adequate sources to determine the issue. On any given farm, the planting of rape and turnips would have reduced the demands on grazing during the winter when brown, waning grass could not regenerate and the roots were vulnerable to over-grazing, thus posing the risk of soil exposure and erosion. Instead, the more intensive cultivation of planted fields as well as a shift towards a larger percent of planted acreage produced both fodder and food that could be stored during the winter.

III. Rapeseed for Green Fallowing

B. napus was also frequently combined with turnips to accomplish a second primary goal of convertible husbandry—the reduction or replacement of bare fallow with a planted crop cycle of forage or feed to increase manure inputs and productivity. In October 1775, improver William Marshall planted a fallow for wheat by dividing the field between turnips and rape. He found that rape was the preferred food when he folded in a hundred sheep at the latter end of September. "They ate the rape down to the clods, before they touched a turnep (or rather turnep tops)," wrote Marshall. After the sheep had been turned in a few days "one side of the field

[67] Ibid.

looked like a fallow, the other like turneps untouched," he added.[68] Marshall recommended two alternative strategies—plough the green rape fallow for wheat into the earth or graze livestock to increase manure inputs. With the latter option, farmers could avoid the cost and difficulty of purchasing manure and spreading it by cart by folding sheep into rape fields. Marshall recommended that a fallow be thoroughly cleaned from root weeds and sown "with the seeds of some quick-growing herbage, in the wane of July, or the beginning of August…."[69]

Andrew Coventry also listed rapeseed as a vehicle for green fallowing. In his 1812 *Notes on the Culture and Cropping of Arable Land*, Coventry wrote:

> And here it may be observed by the way that such fallows though frequently employed are not only expensive in tillage at least rather more so than fallow crops seasonably that is timely introduced and properly conducted but allowing no produce to be gained from which manure may be collected must lessen the fertility of the soil, and so they become in another view ineligible if they could be avoided or were not resorted to as the least of two evils in the way mentioned.[70] [71]

Coventry advised that the chief species composing "this great and important class of fallow crops" were "potatoes, turnips, cabbages, rape, and beans."[72] These fodders were unique for requiring a labor intensive and more advanced planting and tending strategy. They were "raised most commonly and very properly in rows" and were "cleaned both by horse hoeing and hand hoeing and at times or where requisite by hand weeding," wrote Coventry.[73] By highlighting the labor and technical demands of robust fodder production, Coventry details the sorts of logistical constraints that required site-specific trial and error.

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[68] William Marshall, *Minutes, Experiments, Observations and General Remarks on Agriculture in the Southern Counties to Which Is Prefixed, a Sketch of the Vale of London and an Outline of Its Rural Economy*, New ed. ed., 2 vols., vol. 1; (London: Printed for G. Nicol, 1799), p. 184.
[69] Ibid., p. 143.
[70] Andrew Coventry, *Notes on the Culture and Cropping of Arable Land*, ed. Andrew Coventry (Edinburgh: Printed by J. Johnstone, 1812), p. 42.
[71] Ibid.
[72] Ibid.
[73] Ibid.

Such rapeseed fallows also contributed the additional benefits of pest control. According to works like the 1820 *A Treatise on Mildew and the Cultivation of Wheat*, a fallow cycle of rape deprived the wireworms of food while exposing them to the elements. However "In cases where the land cannot have the advantage of an entire fallow, mangel wurzel or rape should be substituted for the turnip crop as those vegetables are less liable than turnips to be injured by the ravages of the wire worm," wrote Josiah Twamley.[74] In this example, rape once again ensured crop success in situations where environmental constraint limited husbandry options. While the bare fallow was preferred, a planted fallow of rape was incorporated as a second option.

In other examples rapeseed was simply combined with turnips to manage fallows in a way that supported animal grazing. In 1776, Matthew Peters described in *Agricultura: or the Good Husbandman* that land should either be left for a veer and ridge winter fallow or sown with rape and turnips to pen off for sheep.[75] William Humphrey Marshall recommended in 1808 that a skillful husband might properly manage his fallow to support a crop of turnips, "or where the land is not for turnips, of rape, cole seed, &c. The produce to be eaten down where grown, or the crops might be varied in other respects."[76] Similarly, "in Ryedale and the Marishes and in some parts of the Vale of York, where the land [was] not dry enough for turnips, rape [was] *sown upon the fallows* which [were] eaten off with sheep in time to sow them with wheat," wrote John Tuke in the 1794 *General View of the Agriculture of the North Riding of Yorkshire with Observations*

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[74] Josiah Twamley, *Essays on the Management of the Dairy: Including the Modern Practice of the Best Districts in the Manufacture of Cheese and Butter* (J. Harding, 1816), p. 16.
[75] Matthew Peters, *Agricultura, or, the Good Husbandman Being a Tract of Antient and Modern Experimental Observations on the Green Vegetable System: Interspersed with Exemplary Remarks on the Police of Other Nations: To Promote Industry, Self-Love, and Public Good, by Reducing Forests, Chaces, and Heaths into Farms: Together with Some Observations on the Large Exports That Must Unavoidably Arise from Thence, as Well as the Increase of Population*, Goldsmiths'-Kress Library of Economic Literature ; (London: Printed for W. Flexney, 1776), p. 54.
[76] William Humphrey Marshall, *A Review of the Reports to the Board of Agriculture: From the Northern Department of England*, ed. Agriculture Board of (London : (York: Printed for Longman, Hurst, Rees, and Orme, T. Wilson), 1808), p. 53.

on the Means of its Improvement.[77] By detailing plantings of rapeseed and turnips for animal grazing on fallow lands, farmers maximized economic gains and protected against crop failure.

To understand the economic importance of *B. napus* and turnips in modifying fallow designs for grazing, we must first explore the appearance of green fallowing in the convertible husbandry literature. John Sinclair noted this relationship in *An account of the Systems of Husbandry* when he wrote:

> The convertible system of husbandry, or alternate crops of grain and green crops, *including the abolition of fallows on turnip soils*, is completely established in Scotland; and is by far the best mode that has hitherto been suggested, for the productive cultivation of a much larger proportion of land, than is generally believed to be the case.[78]

Here Sinclair deviates from our popular contemporary definition of convertible husbandry as a rotation between grassland and arable. Instead, Sinclair also describes convertible husbandry by the rotation of food and fodder via the abolition of bare fallows, which exposed soils to the elements and are now known to increase erosion and nutrient leaching. In this case, the grazing or "grass" phase of the cycle would have been accomplished with planted green crops like turnips or rape. Sinclair specifically notes the benefit of planting such fodders in place of a bare fallow. In other words, instead of uncovered, tilled soil that stood exposed to rain and air—a tactic that allowed root matter to compost and release nutrition into the earth while the soil regenerated and absorbed nitrogen from the rain—a plating of rape or turnips was grazed to increase the quality of the soil. Planted fodder took the place of natural grass but gave the farmer more control over nutritional value and timing of field maturity.

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[77] John Tuke, *General View of the Agriculture of the North Riding of Yorkshire with Observations on the Means of Its Improvement*, ed. Agriculture Board of, Goldsmiths'-Kress Library of Economic Literature ; (London: Printed by W. Bulmer, 1794), p. 33.

[78] John Sinclair, *An Account of the Systems of Husbandry Adopted in the More Improved Districts of Scotland, and a General View of the Principles on Which They Are Respectively Founded*, ed. Board of Agriculture (Scotland : Edinburgh: D.N., A. Smellie, 1809), p. 9.

As to the importance of *B. napus* to this design, Sinclair also highlighted the plant's importance to the planted fallow. Sinclair noted that *B. napus* was even preferred on clays, where instead of a naked fallow on these poor soils, rape and cole support future "beneficial" crops of red wheat. In the same work Sinclair wrote:

> A most intelligent correspondent on the borders, informs that the best way he ever knew of treating clay soils is, *instead of naked fallow, to sow rape or cole* (as it is called in the southern counties of England) in drills, with a little dung in the drills. The crop may be eaten off in August, or the beginning of September, and then wheat may be sown.[79]

This increased land use efficiency by bringing more total acreage into constant cultivation. Wheat no longer required the delay of a soil regeneration period implemented through fallow. By converting unproductive land to fodder, herd size increased along with manure and crop yields. In fact, Sinclair included an entire section written by George Culley titled "On the Culture of Rape, Instead of a Summer-Fallow on Thin Clay Soils."[80] His central argument compared wheat crops after rape to those after naked fallow to show the benefits of more efficient land use. He wrote "…invariably the rape of wheat was better in every respect, than that after naked fallow."[81]

A similar strategy was used to convert arable land to permanent grazing via a transition fallow of *B. napus*. In *The Code of Agriculture* Sinclair wrote "To do justice to the plan of restoring the land to grass there ought to be in all cases according to the soil either a naked or a

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[79] *An Account of the Systems of Husbandry Adopted in the More Improved Districts of Scotland with Some Observations on the Improvements of Which They Are Susceptible*, ed. Agriculture Board of and John Sir Sinclair, 2nd ed. ed., 2 vols., vol. 1 (Edinburgh : (Edinburgh: Printed for A. Constable, J. Ballantyne), 1813), p. 256.
[80] *An Account of the Systems of Husbandry Adopted in the More Improved Districts of Scotland; with Some Observations on the Improvements of Which They Are Susceptible. Drawn up for the Consideration of the Board of Agriculture with a View of Explaining How Far Those Systems Are Applicable to the Less Cultivated Parts in England and Scotland.*, ed. Board of Agriculture, The 3d ed. ... ed., 2 vols., vol. 2 (Edinburgh: A. Constable, 1814), p. 45, Section XL.
[81] Ibid., p. 46.

turnip fallow before the sowing of grass seeds be attempted."[82] A table of crops by soil type listed rape on chalk and peat with turnips on sand, chalk, peat, and loam.[83] In this example, *B. napus* once again supported crop diversification on the poorer of soils. While Sinclair was qualitative with his descriptions and controlled field tests exceed period practice, it is clear that *B. napus* played an important role in replacing bare fallows with a productive cycle.

Arthur Young was similarly enthused and went so far as to ennoble the "anti-fallowists" by praising their use of *B. napus* for grazing in place of grass. Young divided the world between the "fallowists" and the "anti-fallowists." The preponderance of farmers sided with the "anti-fallowists" by claiming that "by the substitution of fallowing crops, on some particular soils, fallows, may be excluded to very great advantage; and it appears; (at least probable) that by a proper combination and succession of turnips, rape, beans, pease, summer and winter vetches, buck-wheat, and rye, a succedaneum [for the bare fallow] may be obtained."[84] Young wrote that "opulent, well-educated and considerable farmers whose enlightened minds have consigned to the graves of their ancestors all repugnant obstinacy…." folded their flocks at night on fallows of rape and turnips "fed off as preparation the same season for wheat."[85] The chief purpose of the bare fallow was to cleanse and pulverize the soil in preparation of wheat, but as Young wrote, crops planted over a bare fallow accomplished this same goal because they supported sheep or

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[82] John Sinclair, *The Code of Agriculture, Including Observations on Gardens, Orchards, Woods and Plantations*, ed. Neely Sherwood, Jones, and John Sir Sinclair, Second edition. ed. (London: Printed for Sherwood, Neely, and Jones, Paternoster-row [and 4 others in 4 other places], 1819), p. 408.
[83] Ibid., p. 390.
[84] Arthur Young, *Annals of Agriculture, and Other Useful Arts* v. 46 vols., vol. v. 7 (London: Arthur Young, 1786), p. 261.
[85] *Annals of Agriculture, and Other Useful Arts*, v. 46 vols., vol. v. 9 (Bury St. Edmund's: Printed for the editor, by J. Rackham, and sold by William Nicoll, No 51, St. Paul's Church Yard, London, 1788), p. 42. https://hdl.handle.net/2027/osu.32435055823223

cattle.[86] Hence the convertible husbandry model was invoked as a sign of modernity in terms of increased support for larger herds through planted *B. napus* in place of bare fallows.

Young was well aware of the economic importance of the convertible design and of the role of *B. napus* in achieving monetary gains. In Volume XI of the *Annals*, he similarly recommended planting fallows with turnips and rape to increase livestock and rents. He wrote:

> But how is it possible to raise rents while products remain as they are? And how to improve products but by converting fallows to *turnips, rape*, potatoes, cabbages, tares, clover, &c., adding greatly to the livestock, consequently to the dung… *Turn your fallows to crops, that shall feed cattle*… do this upon an enlarged scale, and never fear but you will grow corn if you can keep cattle and sheep.[87]

In a footnote Young referenced Lord Sheffield's "great and successful experiment of keeping flock in the weald," which was characterized by poor, chalky soils. He noted that if the "weald would be covered with sheep instead of fallows" and its husbandry improved, the tenants would grow rich at higher rents instead of growing poorer as they were at present.[88] Young returned to this model throughout the *Annals* by recommending "rape sometimes instead of turnips, and sometimes a clean fallow," to improve gravelly, clay and poor soils.[89]

Young wanted to move beyond the historical models of agriculture that dedicated land to either pasture or arable. Yet this precedent left many farmers afraid of modernizing because they believed they could not successfully support both crops and livestock. The two agricultural cycles historically competed for land, labor, and resources. For example, in her 1833 work *Illustrations of Political Economy*, Harriet Martineau relayed a conversation that she had with a family friend, Mr. Malton, about the development of local agriculture. Malton attributed the

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[86] *Annals of Agriculture, and Other Useful Arts* v. 7, p. 261.
[87] *Annals of Agriculture, and Other Useful Arts*, v. 46 vols., vol. v. 11 (London: Arthur Young, 1789), p. 302.
[88] Ibid.
[89] Arthur Young, *Annals of Agriculture, and Other Useful Arts*, v. 46 vols., vol. v. 21 London: Arthur Young, 1793), p. 82.

convertible husbandry design to modern innovation.[90] "You see, Miss Lucy," said Mr. Malton, "it used to be the way for one man to own a certain extent of corn land, and another of pasturage; and, in those days, they did not see the advantage (which is a very important one) of making the corn land into pasture, and growing grain on the grazing land," recounted Martineau of her conversation with Malton.[91] Yet despite the acceptance of the practice, it was best pursued only by those who had "large flocks, as well as a good deal of both sorts of lands," thus highlighting the importance of the larger privatized herds as much as the expanded farm sizes made possible by the transition from common pastures to enclosure.[92]

Here we learn that period actors believed that convertible husbandry was a historically significant process because it supported improvement. The practice of convertible husbandry was defined according to the transition of land functions—most simply, arable became grazing, and grazing became arable. But the mechanisms of convertible husbandry were more fundamental because the process of land transition required multiple modifications. Farmers did not simply move hedges to re-designate the land for an alternative function. Along with increasing winter feed sources, draining or irrigating, paring and burning, removing or planting grass, and marling or manuring, the spatial and chronological cycle of planting and fallowing was altered to strategically use crops that nurtured the soil and served as grazing fodder for manuring. As Martineau, Sinclair, and Young suggest, while it required planning to keep a large herd of cattle and sheep on a farm without access to commons, this process also privatized manure and thus created the mechanism by which crops could be produced on the same acreage.

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[90] Harriet Martineau, *Brooke and Brooke Farm. A Tale*, ed. Harriet Martineau, 9 vols., vol. 1, Illustrations of Political Economy (London: C. Fox, 1833), p. 97.
[91] Ibid.
[92] Ibid.

As a form of convertible husbandry, the transition of bare fallows to planted fallows achieved food for the cattle while also preparing soils for sustained cash crop production. We see this transition in the following example. According to the *The Rural Cyclopedia*, the fallow cycle sometimes spanned a month and served as a break in the rotation, though farmers otherwise experimented with a full year or two of planted cycles that were tilled into the earth so that vegetable products could be consumed by the ground and converted to green manure. This did away with weeds and changed the structure of the soil. John Wilson wrote:

> …vegetable nutrition ought to be returned to the spot and all processes of fallowing whether green fallowing or of bare fallowing requisite to the thorough destruction of weeds and poor grasses to the full play of the forces of natural chemistry and to the complete very fine pulverization of the soil ought to be unsparingly performed.[93]

To this end, the fallow was used to cleanse and purify the land. However as manure offered many of the same benefits, the role of the fallow was called into question when larger herd sizes could finally be sustained.

Young wrote that animal herds contributed many of the same benefits as bare fallows. He wrote "…no one can hesitate, to which to give the preference, as it will be self-evident, that the management which provides provision for livestock, and at the same time, manure[d] and cleanse[d] the land must have the superiority over a barren fallow."[94] An 1803 entry in the *Agricultural Magazine* similarly lists rape as part of a summer fallowing practice that pulverized, aerated, and even hydrated the soil:

> It cannot, indeed, be disputed, but that the practice of summer fallowing, may be greatly lessened in many districts by the proper substituting of green fallows, or what are termed fallow crops, such as beans, peas, cabbages, tares, and rape, for the heavier sorts of land; and buck wheat, potatoes, and turnips, for such as are of the lighter kind.…

[93] John M. Wilson, *The Rural Cyclopedia, or a General Dictionary of Agriculture : And of the Arts, Sciences, Instruments, and Practice, Necessary to the Farmer, Stockfarmer, Gardener, Forester, Landsteward, Farrier, &C*, ed. John M. Wilson, 4 vols., vol. 2 (Edinburgh ; London: A. Fullarton, 1851), p. 510.
[94] Young, *Annals of Agriculture, and Other Useful Arts* v. 7, p. 261-2.

In this example, rape and other fallows are said to increase fertility and prevent soil evaporation.[95] These two excerpts highlight the complex site-specific nature of eighteenth century environmental designs. Though both crops could be planted on a wide range of soils, rapeseed is recommended for heavier soils while turnips flourished on lighter lands. The quality of the hoeing is acknowledged as an instrumental part of the system, which suggests attention to both the management of topsoil and the spacing of plants during the growing cycle. The point is not whether most farmers of the period adopted the same exact strategy—to the contrary, in other sources rapeseed is recommended for the light silt and sandy soils via the implementation of alternative design strategies. Rather, the conceptual understanding in this quote is of interest for linking a mechanism—in this case pulverization, aeration, or the prevention of evaporation—to unique pairings of cover crops by soil type. Increased fertility relied upon the site-specific uses of the fodders. The fact that this varied by farmer and locality illustrates the modular adaptation of designs based on a customized interpretation of environmental variables.

This growing awareness of environmental design occurred at least as early as the mid-eighteenth century. In the 1750s, William Ellis born as a humble farmer and with only a basic education began publishing prolific volume after volume on this modern husbandry. Based in part on his experiences running a farm called Little Gaddesden in Hertfordshire, his work contains numerous references to rapeseed combining, and shows that farmers strategically used rape and turnips to work the land towards a cash crop cycle. The accounts published by Ellis are important for documenting the early widespread use of the technology and for highlighting the

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[95] H. N., "On Fallowing Land," *Agricultural magazine* 8, no. 44 (1803), p. 194.

benefits of integrating rapeseed and other fodders into convertible husbandry. For example, in the year William Ellis wrote in *The Modern Husbandman*:

> …such Land may, by only one or two Plowings at most, be brought into a fine Tilth, fine enough for receiving Turnep Seed of the forward sort… they may be drawn or fed off time enough to sow the same Field with Rape Seed; and, after these are done, a Wheat Crop, or a Barley Crop, may be let on the same; and all this performed without the Help of carrying any Dung or Manure to the Field, provided such Thetches, Turneps, and Rapes, are fed off with Sheep; for by this Means the Ground will be full rich enough to carry forward any of these After-crop to great Perfection, because the Weeds will be crippled, and the Land plentifully stored, and furnished with the nitrous Qualities of the Sheeps Dung and Urine.[96]

First, it is important to note that Ellis describes planting *B. napus* independently and in place of turnips to facilitate the practice of convertible husbandry through green fallowing. Ellis used rapeseed both as a fodder to create an alternative to turnips and as a combinatorial option that increased turnip crop protection. Second, it is important that *B. napus* combined with manure helped purify the soils of weeds, as noted by Young and others nearly half a century later. Finally, here again *B. napus* performed especially well on peaty, boggy, and chalky grazing lands that suffered from poor soil quality and could support few types of crops after tillage. In these ways *B. napus* contributed a safety mechanism that was important to farmers in the early and mid-eighteenth century and only modernized as mechanical innovation progressed.

The detailed specifications for drilling rapeseed illustrate the attention to the design parameters of plant spacing even when executing new innovations. The success of new drilling machines depended upon the customization of spacing for different rates of application for a fallow of fodder. The reliability of fodder crops depended largely on spacing and the depth of planting, and drilling replaced less precise broadcast methods as well as the more labor intensive

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[96] William Ellis, *The Modern Husbandman, or, the Practice of Farming. Containing the Months of January, February, and March.* , v. 4 vols., vol. v. 3 (London: Printed for, and sold by T. Osborne and M. Cooper, 1744), p. 78-90.

practices of poking holes in raised soils and covering. Fordyce Mayor of Berkshire confirms that while rape was often broadcast sown at the rate of two pounds of seed per acre, it was also drilled using far less seed at twelve or fourteen inches.[97] William Amos highlighted the importance of spacing turnips and rape and the additional control made possible with the seed drill in *The Theory and Practice of the Drill in Husbandry*. He wrote in a segment titled *On drilling Turnips and Rape*: "Having prepared the seed as directed before, nothing more is necessary to be done, but to reverse the seed wheels, and fix the coulters at the distance at which you intend the rows to be asunder."[98] On poor soils he found that ten inches was the best distance, but on rich ones twelve inches was ideal. He advised that about one inch was the best depth. "When turnips are sown at a greater distance, they grow too large for keeping long," he added. On very rich soils, a greater distance may be advisable, but then they should be eaten off before Christmas.[99] Richard North, a nursery gardener, wrote that rape plants should be spaced a little closer, but he still emphasized the importance of hoeing even for crops that would be used for feed. In *An Account of the different kinds of Grasses propagated in England,* North advised sowing rape in July at a rate of three or four quarters to an acre. He wrote:

> The Seed should be harrowed in as is directed for Turnips. It would be much better for the Crop in every respect if the young Plants were hoed once over and left about eight or ten Inches apart. When Rape is large and rank it may be fed with Sheep in February and March and afterwards let run for Seed, but it is frequently sown merely for Food for Cattle. The Land is frequently continued in Tillage some Years after a Crop of Rape.[100]

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[97] William Fordyce Mavor, *General View of the Agriculture of Berkshire*, ed. Agriculture Board of (London Printed for Sherwood, Neely, and Jones, 1813), p. 219.
[98] William Amos, *The Theory and Practice of the Drill Husbandry Founded Upon Philosophical Principles, and Confirmed by Experience ... Illustrated with Exact Drawings of All the Respective Parts, and a Perspective View of Each Machine Compleat on Nine Copper Plates, Whereby Every Farmer Will Be Enabled to Make His Own Drill Machines*, 2nd ed. ed., Goldsmiths'-Kress Library of Economic Literature ; (S.l.: s.n., 1802), p. 194.
[99] Ibid.
[100] Richard North, *An Account of the Different Kinds of Grasses Propagated in England, for the Improvement of Corn and Pasture Lands, Lawns and Walks with Many Useful Directions for Sowing Them, Manuring, &C. ... And the Best Directions for Raising Turnips, Rape, Cabbage, &C. ... Also an Account of the Manures ... With Directions for Trench-Plowing : Likewise an Account of the Sound-Growing Norfolk-Willow : With Directions for Propagating It to Great Advantage* (London: Printed by W. Prat, 1759), p. 19.

The integration of these multiple uses of the same planting of rape for fodder, feedstuff, oilseed, and soil improved land use potential after planting. However this excerpt also combines the technical knowledge of rate of seeding, spacing, and depth of planting with the different preparations for unique soil types. As spacing can determine germination and root hold at every stage, rapeseed meal supported more robust crops of turnips, which in turn helped feed larger herds. By developing cultivation practices that integrated waste from oil crushing back into the soils, farmers paved the way for better crops of fodder and thus herds of a larger sustained size.

Rapeseed meal green manuring was thus critical in overcoming the age-old environmental limits related to the soil demands of green fallowing. To maintain a larger herd, it was necessary to produce fodder on site; yet fodder production required manuring in order to ensure a robust feed and forage crop. Without manure for fodder, the land would struggle to produce enough feed for animals and the soil would become quickly starved of nutrients for future crop cycles. Thus, a farmer needed manure to produce manure. We have already discussed the first way that rapeseed helped overcome this problem—as a fodder that flourished on poor soils and in harsh growing conditions, it could be grown on waste lands and thus expanded manuring to marsh and moor that otherwise supported less productivity. However rapeseed meal manuring also brought fallows into fertility by supporting turnip plantings. The meal, crushed onsite or bought in bulk by the oilseed press, was tilled into soils or broadcast onto turned earth. Even without our modern scientific concepts of nutrient cycling, period farmers were well aware that rapeseed meal as a fallow manure overcame environmental limits.

Beyond the question of rape as a crop on fallow, we must now consider *Brassica napus* as an ingredient in rape cakes. By the end of the eighteenth century, rapeseed meal was spread at a controlled rate with the seed drill. In the 1813 the Board of Agriculture offers numerous examples in the *General View of the Agriculture of the County of Norfolk* that illustrate the use of rape cake as a manure for turnips and describes the use of both large and small cups "for the delivery of both cake and seed into the same drills."[101] The work describes that "The grand fallow of Norfolk is the preparation for turnips… the common summer-fallow takes place on strong, wet, and clayey soils; upon which, however turnips are too generally ventured."[102]

This integration of rapeseed meal was thought to support larger herds by extending the land's ability to produce ongoing crops of fodder. Thomas Wedge described the use of this technology in the County of Palatine of Chester, though he viewed *B. napus* cake as helpful rather than essential to growing turnips for milk cows or cattle. In 1794 Wedge wrote that if "a hand manure such as soot, pigeons dung, rape-dust, or the like can be conveniently had, it might be prudent to use it, but if not, there is no doubt that a good crop of turnip would be obtained without it."[103] A similar recommendation appears in John Tuke's *General View of the County of the North Riding of Yorkshire,* which recommends rape-cake for turnip fallows.[104] While many examples highlight the use of rapeseed meal as a manure for turnips, these example more specifically show the use of this strategy to produce turnips for green fallow grazing.

While manuring is often thought more likely to increase yields per acre, the combining of rape cake for turnip fallows illustrates the role of more efficient land use in period gains in total net product. Each acre of bare fallow ultimately yielded nothing while regenerating, though this cycle might have been important to sustaining higher yields over the long term. When new

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[101] Board of Agriculture, *General View of the Agriculture of the County of Norfolk*, ed. Arthur Young and Board of Agriculture (London : (London: Printed for Sherwood, Neely, and Jones, B. McMillan), 1813), p. 418-20.
[102] Ibid., p. 192.
[103] Thomas Wedge, *General View of the Agriculture of the County Palatine of Chester with Observations on the Means of Its Improvement*, ed. Agriculture Board of, Goldsmiths'-Kress Library of Economic Literature ; (London: Printed by C. Macrae, 1794), p. 100.
[104] Tuke, *General View of the Agriculture of the North Riding of Yorkshire with Observations on the Means of Its Improvement*, p. 100.

fodder designs facilitated grazed fallows without compromising soil quality or long term yields, the average yearly ratio of planted acreage would have increased. The expansion of arable or grazing acres through the conversion of moor, marsh, and waste is more often cited as the cause of increases in net agricultural product, and such examples help explain why net primary product increased even when yields per acre decreased or remained stagnant.[105] For this reason increased net product is sometimes dismissed as a sign of true gains in soil fecundity or agricultural improvement. However as this study of *B. napus* shows, the conversion of bare to grazed fallow not only increased product while contributing manure to the soil, but also freed some permanent pasture acreage for planting. Thus, increased land use efficiency during the eighteenth century marks an important period boundary. While each aspect of this design can be traced in some capacity to the seventeenth century, it is only in the mid- to late eighteenth century that reports widely illustrate the integration of *B. napus* manuring and fodder plantings with turnips for grazed fallow cycles as part of a convertible model.

As we will see in the next section, the integration of *B. napus* manure and fodder into convertible designs ultimately re-scaled the percent distributions of grazing and arable at the level of individual farms in ways that was not easily accomplished during prior centuries. While herds and the nitrogen they contributed could not increase without new fodder supplies, it turns out that the integration of fodders and food stuffs like rapeseed required a change in land use towards convertible husbandry at a larger scale of management than was possible under common

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[105] One good example is Howell's coversion of 3,000 acres of sandy coastal land and more to rape for grazing. He was then able to begin planting wheat on suitiabal lands thanks to the manure contributions. Adam also expands upon this. Great Britain. Parliament. House of Commons, "Parliamentary Papers," p. 35-6; Adam, *Practical Essays on Agriculture : Containing an Account of Soils, and the Manner of Correcting Them. An Account of the Culture of All Field Plants . Also, an Account of the Culture and Management of Grass-Lands; Together with Observations on Enclosures, Fences, Farms, and Farmhouses, &C. Carefully Collected and Digested from the Most Eminent Authors, with Experimental Remarks*.

use grazing. This required more control through new technologies and better designs for each county and regional geography, including detailed temporal and spatial planting knowledge.

IV. Scaling Rapeseed and Turnips to the Landscape-level in Convertible Husbandry

Many historians believe that the introduction of new nitrogen fixing fodders helped early modern and eighteenth century farmers overcome this limit to growth. As manorial landlords generally favored the expansion of grain acreage into pasture but lacked the fodder technologies used in the grazing rotations of the late eighteenth century, it is widely believed that market growth was limited by nitrogen depletion. Privatized land rights are thought to have helped resolve this problem by allowing farmers to integrate fodders into arable plots. It was only the introduction of new fodder species during the early modern period that allowed convertible husbandry to begin surpassing the productive output of common land tenure.

Yet most renditions of the nitrogen thesis assume a take-off model of fodder technology. The introduction of new fodders is described as a springboard for the British Agricultural Revolution and a break from the pre-modern landscape. In contrast, this section develops a reciprocal co-determination between herd size and new fodders in which the introduction of *B. napus*, turnips, and legumes required the increased manure and agricultural integrity of a farming system that had already come to support more livestock and begun to integrate animals from common fields into privatized lease structures for a rotation of forage and arable. I propose a revisionist model of fodder takeoff in which nitrogen fixing fodders were insufficient to meet demand and rapeseed formed a positive feedback loop with herd size to permanently alter edaphic conditions at the regional scale. More than the number of farms using convertible husbandry or the widespread adoption of the technique across many counties, this chapter considers eighteenth-century understandings of the total percentage of land dedicated to grazing, arable, or any land use type. Eighteenth-century farmers strategically began to alter larger portions of their farm through more rapid convertible cycles customized to meet the needs of soil type, climate, and economic demand. Even if *B. napus* was not as frequently planted as clover, it was just as influential as the nitrogen fixing fodders based on the role it played in the agronomics of scale. Net product increased as bogs, moor, and wasteland were incorporated into *B. napus* fodder for grazing.

To develop this thesis, I begin by considering the landscape-level role of *B. napus* in eighteenth and early nineteenth century organic designs before synthetic nitrate and phosphate inputs began to drive productivity gains. I then explore the introduction history. *B. napus* was introduced from France for industrial scale plantings due to a 1624 patent for oil crushing, and this placed *B. napus* in the landscape many decades before the nitrogen fixing fodders were first tried at the small scale in botanic gardens.[106] If the long history of British enclosure culminated in any advantage, it was by re-designing continental technologies to flourish in England's cooler summers and warmer winters and by site-specific design innovation that tested combinations in the diverse microclimates and soils of the maritime island. This land-scape level transformation, which altered the spatial design of the countryside in terms of the relative percent of grazing and arable, is what distinguishes the farms of the late eighteenth century from earlier examples.

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[106] For the introduction of rapeseed: Sovereign England and Wales and King of England James I, "James, by the Grace of God, King of England, Scotland, France, and Ireland, Defender of the Faith, &C. To All to Whome These Presents Shall Come, Greeting Whereas Our Welbeloued Subiect, Benedict Webbe, of Kingeswood, Clothier, Hauing in His Trauell, Obserued a Kinde of Oyle to Bee Made of Rape-Seede," ([London :: F. Kingston Ann Arbor, MI Oxford (UK) :: Text Creation Partnership], 1624); Thirsk, *Alternative Agriculture: A History from the Black Death to the Present Day*, p. 72-9. Mauro Ambrosoli, *The Wild and the Sown : Botany and Agriculture in Western Europe, 1350-1850*, ed; Thirsk Joan, Past and Present Publications (Cambridge England ; New York: Cambridge University Press, 1997), p. 85; Kerridge, "Turnip Husbandry in High Suffolk." Mark Overton, "The Diffusion of Agricultural Innovations in Early Modern England: Turnips and Clover in Norfolk and Suffolk, 1580-1740," *Transactions of the Institute of British Geographers* 10, no. 2 (1985).

"Convertible husbandry is a system capable of endless modifications," wrote Harry Kitsikopoulos in his 2004 work *Convertible Husbandry vs. Regular Common Fields*.[107] Though many date convertible husbandry to the eighteenth century, Kitsikopoulos traces the practice to the pre-plague period in England. He builds upon the research of Michael Moissey Poston, who argued that "the frontier between corn and grass was always on the move" in the Middle Ages due to nascent convertible designs.[108] Based on anecdotal examples, it is well known that convertible husbandry was practiced even during historical periods when herds were small. Gregory Clark described a manor in Wiltshire where 33 acres of arable were converted to ox pasture and then plowed again around 1314.[109]

Kitsikopoulos built upon this literature with a case-study comparison of the yields per acre, seeding rates, percentage of sown acres, and the price in shillings per bushel of wheat, barley, oats, rye, and legumes between twenty five sights that practiced convertible or composite husbandry during spans of time in the thirteenth to fifteenth centuries, depending on the data set. By relying on data sets compiled by Bruce Campbell in *A Medieval Capital and its Grain Supply* and *The Demesne Farming of Post-Black Death England*, he shows convertible patterns at least as early as 1280.[110] Yet unlike the late eighteenth century case examples of convertible husbandry, which widely show increases in livestock productivity as well as increases in net product and yields per acre, Kitsikopoulos argued that Medieval net output was about a third higher on demesnes that practiced permanent tillage and pasture when compared to those that

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107 Harry Kitsikopoulos, "Convertible Husbandry Vs. Regular Common Fields: A Model on the Relative Efficiency of Medieval Field Systems," *The Journal of Economic History* 64, no. 2 (2004), p. 463.
108 M. M. Postan, "Medieval Agrarian Society in Its Prime. 7. England," in *The Cambridge Economic History of Europe from the Decline of the Roman Empire*, ed. M. M. Postan (Cambridge: Cambridge, 1966), p. 552.
109 Gregory Clark, "The Economics of Exhaustion, the Postan Thesis, and the Agricultural Revolution," *The Journal of Economic History* 52, no. 1 (1992), p. 68.
110 Ibid., p. 486-7.

used convertible husbandry. The total net output of composite acres in pre-plague years was about 8.82 bushels compared to 6.93 for convertible management. In contrast, by the seventeenth century, Walter Blith boasted that convertible husbandry provided three times as much output as common fields per acre. John Laurence showed that farmers who adopted convertible husbandry in the middle of the eighteenth century produced 20 bushels per acre.[111]

As to the reason for such low productivity in the Middle Ages, Kitsikopoulos believed that foddering practices was rudimentary, edaphic conditions such as soil drainage were poor, and land management was irregular. Kitsikopoulous wrote:

> …the productivity of convertible husbandry during the Middle Ages fell short of its early modern counterpart because of the presence of a fundamental element that was present in the latter period but absent in the former, that is, fodder legumes whose nitrifying properties have the capacity to provide a tremendous boost to the level of grain yields.[112]

The majority of the manors included in the study adopted the design on light soils, which harmed the retention of nitrogen and thus grain yields, argued Kitsikopoulous. Indeed, such soil conditions may have motivated experiments with alternative planting strategies. If common arable plots began to deteriorate, the village would have faced scarcity and the tremendous labour needed to rotate fields and pasture might have been worth the investment. In any case, it is clear that demographic pressures in the form of rapid population growth in areas that relied on sandy or light soils led to agricultural intensification and expansion of arable acreage in the form of displaced field rotations and ley pasture. Manure supplies were relatively meager in the period, and the more diverse options such as clover, turnips, *B. napus*, sainfoin, and Lucern available in the eighteenth century were not yet introduced.

[111] Ibid., p. 465-66.
[112] Ibid., p. 464.

I will argue here that Kitsikopoulous exaggerates the importance of early introduction. In fact, W. Wealands Robson accurately described the paucity of meat in the late seventeenth century, when shortages continued even despite the introduction new fodders were introduced.[113] Fodder introduction was neither a solution to the scarcity of meat nor the sole reason that herds began to grow. Rather, fodder development was predicated upon increased manure inputs, and the whole system in which new feeds supported increased herd size required temporal and spatial design innovation. Thus, the history of *B. napus* plantings sheds new light on the importance and limitations of privatized land tenure in the development of the site-specific designs which scaled convertible husbandry to the landscape level. I argue that it was the evolution of fodder and herd management designs more than their introduction or disbursal that supported larger-scale projects.

Let us begin with an example from the period literature that demonstrates the scaling of environmental impacts from rapeseed to the landscape level. It is astounding that our historical actor Arthur Young published observed estimates of increased fecundity from *B. napus* innovation that exceed even modern estimates published by the economic historians who attempted to reconstruct period production functions using Young's work. Timmer published the best work on the importance of turnips in convertible husbandry to show a meager 10% increase in grain yields via a 33% increase in animal units for a conversion of 240 acres of fallow and pasture to turnip and clover husbandry.[114] He based this model on Arthur Young's description of a 500 acre farm on light soil, which would have supported 2,400 loads of manure by grazing 67 animal units. Under turnip cultivation, Young's farm would have produced 3,600 loads of manure with 100 animal units. In Timmer's model, the old farm begins with 120 acres

[113] Robson, "Turnip Husbandry," p. 101-02.
[114] Timmer, "The Turnip, the New Husbandry, and the English Agricultural Revolution," p. 386.

of wheat, barley, and fallow plus 140 acres of grass. The new farm imagined by Timmer maintains this acreage but transitions 120 acres of fallow to turnips and 120 acres of grass to clover, leaving only 20 acres of permanent grazing land.[115] By assuming a 20 percent increase in wheat and barley yields for every doubling of manure, Timmer estimates that the 500 acre farm would have only seen a 10 percent increase in yields.[116]

We can trace an even tighter correlation between coleseed and herd size with period sources**.** According to empirical accounts offered by Arthur Young in the *General View of the Agriculture of the County of Sussex*, it only took fifteen acres of turnips and 10 acres of cole near Weald the Down to support 100 animal units or 1,000 sheep.[117] Similarly, Young writes that in Adfriston Parish, 45 animal units or 450 sheep were supported on only six acres of coleseed plus eight or nine tons of hay. This demonstrates a far greater land use efficiency than was shown by Timmer's turnip-based model. In fact, Timmer's 100 animal units supported on 500 acres represents a 20% heard density while Young achieved 6.6% for the same 100 animal units. Most impressively, Young also shows that small plot of rape of only six acres could support as many as 45 sheep with 8 or 9 loads of hay.[118] Larger plots also supported increased herd sizes thanks to rapeseed plantings. On Young's larger farm of 1667 acres, as many as 442 new animal units were supported in addition to 200 head of horned cattle after the adoption of rapeseed. As two oxen or ten sheep could graze the same two acres, one animal unit was equal to one horse which equated to either two oxen or ten sheep. Both examples represent a system of metrics by which

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[115] The 120 acres of turnips are equal to 60 acres of clover or grass because turnips lasted for only about four months between the grazing and root stock feed produced.
[116] Timmer, "The Turnip, the New Husbandry, and the English Agricultural Revolution," p. 387-88.
[117] Arthur Young, *General View of the Agriculture of the County of Sussex : With Observations on the Means of Its Improvement*, ed. Agriculture Board of (London: Printed by J. Nichols, 1793), p. 68-70.
[118] Ibid., p. 69.

one horse accounts for a single animal unit based on its need for two acres of clover or grass per year for support.

While we must be cautious when drawing conclusions from such estimates, it is clear that Timmer's simplified model falls far short of representing the benefits of land efficiency from convertible husbandry as it was perceived by historical actors who published similar accountings of livestock productions in the period. Young reports the period equivalencies, while Timmer extrapolates a model from historical accounts. Like so many historians and agricultural

Table 3.2 *The Old and New Farm*

Old Farm (acres)	Crop	New Farm (acres)
120	Wheat	120
120	Barley	120
120	Fallow	0
0	Turnips	120
0	Clover	120
140	Permanent Grass	20
500	Total	500

Timmer's Old and New Farms show a much lower increase in productivity than is estimated by Arthur Young with the introduction of rapeseed. *Source* Peter Timmer, "The Turnip, the New Husbandry, and the English Agricultural Revolution," *Quarterly Journal of Economics* 83, no. 3 (1969). [119]

economists, Timmer's focus on turnips and clover as the cornerstones of the British Agricultural Revolution neglected the sophistication of an evolving system of agriculture that accomplished far more than an incorporation of new fodder types and a lease structure to allow their planting. Timmer wrote "The primary problem was the rigid form of land cultivation, and the secondary

[119] Timmer, "The Turnip, the New Husbandry, and the English Agricultural Revolution," p. 386.

problem was the inability to carry livestock over the winter. Enclosure solved the former and turnips and clover the later."[120] He cited Chambers and Mingay to focus on the 1750-1880 period of agricultural transformation, and offered 1701 as the earliest date for the establishment of field turnips. Though Timmer summarized competing evidence for a slower introduction following Lord Townshend's 1733 retirement to the country to experiment with agriculture.[121] Yet Timmer's hypothetical 10% increase in grain productivity was very small. In *Yields per Acre in English Agriculture* Clark compared published empirical accounts of wheat yield increases as large as 54%, 50%, and 32% from 1600 to 1700, long before Timmer believed that turnips and enclosure began to reshape production in the second half of the eighteenth century.[122] Though a 10% increase in productivity was economically meaningful during the Middle Ages, this rate of change is less reliable by the late eighteenth century when output fluctuated from farm to farm due to site-specific innovation.[123] Timmer's estimate of a 10% increase in yields is based on a model farm and the model does not show increased productivity on a typical farm.

Studies of *B. napus* shed new light on the debates over yield increases and hypothetical yield increases by shifting focus to the increase in net primary product from internal and external convertible practices. We have already explored the ways in which *B. napus* extended the amount of time that arable acreage located inside a working farm was converted to fodder production or grazing. But in addition to lengthening the seasonal temporality of plantings and increasing the number of bare fallows in cultivation, *B. napus* also increased the acreage of poor soils in cultivation and extended farm boundaries into wasteland through land conversion. We

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[120] Ibid., p. 377.
[121] Ibid., p. 376, 70, 80.
[122] Gregory Clark, "Yields Per Acre in English Agriculture, 1250-1860: Evidence from Labour Inputs," *Economic History Review* 44, no. 3 (1991), p. 448.
[123] "The Economics of Exhaustion, the Postan Thesis, and the Agricultural Revolution," p. 61-2.

cannot assume that rapeseed acted alone to increase land use efficiency on small farms. But by serving as a vehicle for increases in total net product through better land use efficiency, *B. napus* may have had just as great of an environmental impact as the many technologies thought to have spurred increases in yields.

To begin, B. *napus* sometimes out-performed the nitrogen fixing legumes on poor soils and functioned on a wider range of soils. In Cumberland, George Culley wrote in the *General View of the Agriculture* that on dry, sandy, and light soils rye was "frequently sown in August and September, along with rape, as spring feed for sheep which often proves very valuable in the month of April."[124] Though rapeseed was not widely used in Galloway, Samuel Smith wrote in 1810 that it was selected by a farmer named Mr. Cathchart of Genoch for its promise to perform in a large field of sand and clay. After burning, Mr. Cathchart "proposed sowing [the field] with rape-seed."[125] In Cambridge, Charles Vancouver wrote in the 1794 General *View of Agriculture in the County* that in South-well where the clayey loam was mixed with fine sea sand and silt, the soil was proper for the planting of hemp, flax, coleseed, and other crops that performed well in this environment. While turnips were recommended on the loams, coleseed was reserved for the poor, sandy soils.[126] Thomas Stone illustrated a similar niche for rapeseed in 1793 when he designed a reclamation system to convert commons to grazing land. In the *General View of the Agriculture in the County of Huntingdon*, Stone developed rotations of white grains with artificial grasses like rape and turnips. The authors extended this model to the reclamation of

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[124] John Bailey and George Culley, *General View of the Agriculture of the County of Northumberland: With Observations on the Means of Its Improvement: Drawn up for the Consideration of the Board of Agriculture and Internal Improvement*, ed. George Culley, et al. (Newcastle: Printed by Sol. Hodgson, and sold by Mess. Robinson ..., and G. Nicol ..., London, 1797), p. 70.

[125] Samuel Smith, *General View of the Agriculture of Galloway: Comprehending Two Counties, Viz. The Stewartry of Kirkcudbright, and Wigtonshire. With Observations on the Means of Their Improvement.*, ed. Board of Agriculture (London: R. Phillips, 1810), p. 227.

[126] Vancouver, *General View of the Agriculture in the County of Cambridge: With Observations on the Means of Its Improvement. Drawn up for the Consideration of the Board of Agriculture and Internal Improvement.*, p. 154-55.

commons by saying "light loamy, sandy, and gravelly soils if they are in a state of common field, answer best to the proprietors upon an inclosure…" These soils were "very weak, poor, foul, and unproductive" due to the "ancient common-field husbandry" and the "quick repetitions of the same sorts of grain" and the frequent tillage of the light soils "let the mucilage be washed away, and to escape the reach of the roots of the grain. Farmers only increased "the means of improving and supporting cattle and sheep, and very much meliorating their winter layer" when "green winter food [was] produced as cole, or rape or cabbages, where manure, in pretty strong dressings can be afforded for that purpose" wrote Stone.[127] From these examples, we can safely argue that rape performed well on the sorts of sand and mixtures of sand and gravel described by Kitsikopoulos as the primary limitations in Medieval convertible systems.[128]

Rapeseed makes for an interesting case study because it was recommended on both the sandy soils that drained rapidly and the water logged clays and draining marshes. We thus see that farmers carefully pared fodders with soil types according to the environmental demands of water logging and drainage capacity of the soils. The attention to soil type in the above citations is just one example that these design strategies were more than mere guesswork. However rates of application, the number of ploughings and harowings prior to planting, and the resolution of cycles of crop and fodder all point to a careful plan constructed by the grower. As a sign of rapeseed's diversity as a tool, Stone also recommended the plant for clays, known for their poor drainage. In the 1794 printing of the *General View of the Agriculture in the County of Bedford*, Stone wrote that rapeseed was incorporated as part of reclamation systems to convert poor, watery soils to grazing land. While Stone also recommended rape for the light soils in

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[127] Thomas Stone, *General View of the Agriculture of the County of Huntingdon with Observations on the Means of Its Improvement*, ed. Board of Agriculture (London: Printed by J. Nichols, 1793), p. 20.
[128] Kitsikopoulos, "Convertible Husbandry Vs. Regular Common Fields: A Model on the Relative Efficiency of Medieval Field Systems," p. 480.

Huntingdon, he only slightly revised the strategy for the clayey lands of Bedford. He wrote: "Strong clayey land with a shallow staple may be very much improved by means of an inclosure upon which a complete drainage may be effected." He emphasized the importance of rape in the system and suggested a system of convertible husbandry that incorporated rape for winter feed.[129] As a vehicle of convertible husbandry, fodders were selected for their ability to support grazing on each soil type and to convert commons and poor water logged soils to the production of livestock. The additional manure inputs from the animals restructured soils over time by altering the humus content and thus nutrient storage and availability.

Yet not all historians writing in favor of the nitrogen hypothesis agree on the value of manure, and some favor the importance of nitrogen fixing fodders as the central innovation of the period. Robert Allen bases his larger model on legumes and even disputes the importance of animal manure by focusing on the contributions of nitrogen fixation. In his paper titled *The Nitrogen Hypothesis and the English Agricultural Revolution: A Biological Analysis*, Allen favored the plantings of nitrogen fixing peas, beans, and clover during the eighteenth century as the most important nitrogen contributor during the British Industrial Revolution. Allen disputed the large body of work that touted dung as an instrumental source of nitrogen by claiming it merely cycled rather than increased nitrogen:[130] He wrote "the dung [that animals] produced was less important than the food they ate because the dung merely recycled nitrogen in the system (losing much in the process), whereas the cultivation of peas, beans, and clover for fodder raised the stock of soil nitrogen to the benefit of grain production.[131] Grain yields improved in England

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[129] Stone, *General View of the Agriculture of the County of Bedford: With Observations on the Means of Improvement*, p. 62.
[130] Robert Allen, C. , "The Nitrogen Hypothesis and the English Agricultural Revolution: A Biological Analysis," *The Journal of Economic History* 68, no. 1 (2008), p. 184.
[131] Ibid., p. 202.

between the Middle Ages and the industrial revolution because convertible husbandry increased soil nitrogen levels through the use of legumes that both fixed nitrogen and increased the efficiency with which that nitrogen was converted to grain.[132] Allen considers the benefits of manure in terms of nitrogen cycling but dismisses the importance of manure in restructuring humus, increasing nutrient storage and nutrient availability, and altering the biodiversity of the soil microbiome—all factors shown to increase fecundity and yields. He thus entirely omits studies of alternative fodders like *B. napus* which primarily increased manure by supporting larger herds but did not fix nitrogen. Alternative fodders like rapeseed received no attention because the cycle of animals alone was not enough to increase yields without fixation.

Yet it turns out that grain yields began to rise long before nitrogen-fixing clover and Lucern were introduced. In the *Economics of Exhaustion*, Clark critiqued the nitrogen hypothesis for its lack of chronological overlap with historical patterns of grain yield increases. He highlights the "good evidence that substantial grain yield increases were achieved before the widespread use of sown clover in arable rotations.[133] He adds that a major problem with the nitrogen orthodoxy is that "significant increases in yields occurred in England in the seventeenth century, well before the area in sown clover was sufficient to account for any yield increases."[134] Yields were indeed astonishingly low in the Medieval Period—sometimes productivity was close to the planting seed count. Instead of a healthy shaft of wheat full of grain, farmers only ended the season with two or three kernels for each grain planted.[135] "In southern England, in the years before the Black Death, I estimate that the net yield per acre from cultivated land was only

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[132] Ibid.
[133] Clark, "The Economics of Exhaustion, the Postan Thesis, and the Agricultural Revolution," p. 70.
[134] Ibid.
[135] Ibid., p. 61.

equivalent to 4 bushels of wheat, compared to 13 circa 1850," writes Clark.[136] He critiques the Poston thesis, which argued for the expansion of grain into every accessible pasture area during the Middle Ages due to population pressure. According to Poston, nitrogen depletion from increased cultivation was only ameliorated after the plague when populations declined and village farmers had more access to pasture. [137] Yet if this model is right, grain yields per acre should have increased after the plague when population pressure declined and nitrogen once again began to accumulate in pasture and fallows.[138] In fact, grain yields did not increase when the available nitrogen began to increase. As Clark noted, "nor is there any sign of declining yields in the period from 1200 to 1349, as population pressures increased."[139]

Similarly, during the late eighteenth century when nitrogen was likely increasing due to the better integration of legumes and convertible husbandry, Clark shows that the acceleration of grain yield increases dropped below the rate of increase during the seventeenth century.[140] Far from the 30 to 50% increases in wheat yields in the seventeenth century which happened long before the nitrogen fixing legumes could have been widely integrated, we see some accounts of stagnation and plateaued grain yield increases in the mid-and-late eighteenth century when new

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[136] Ibid.
[137] Postan, "Medieval Agrarian Society in Its Prime. 7. England," p. 553-54, 56. Poston argued that villagers even more than their lords were underprovided with pasture. He described innumerable fines imposed on villagers for sheep and cattle straying on to the lord's land. So regular were the fines for trespasses and so numerous were the villagers thus find that historians may be forgiven for concluding that the fined were sometimes little more than supplementary pasture rents disguised as punishments.
[138] Ibid. It turns out that in the Double Hundred of Blackbourn in Suffolk—a region known for its historical legacy of sheep farming—the total animal population in 1283 was only half that in 1867. In other areas, herds were largely confined to manorial pasture and individual villagers owned at most one or two cattle or five or six sheep because they could not afford larger herds. Pastoral estates were largely limited to the highlands and marshes, and "the Medieval Englishman's propensity to concentrate on corn-growing at the expense of sheep-farming or cattle grazing is one of the hallmarks of the economic geography of the thirteenth century," wrote Postan. It is thus no surprise that Postan shows that animal products were consumed by those at a higher income levels. This highlights the potential for nitrogen depletion and soil exhaustion, and establishes a central historiographic model of increased agricultural productivity during the transition from Medieval to modern farming.
[139] Clark, "The Economics of Exhaustion, the Postan Thesis, and the Agricultural Revolution," p. 67.
[140] "Yields Per Acre in English Agriculture, 1250-1860: Evidence from Labour Inputs," p. 54-5.

technologies may have been the most influential.[141] It is thus difficult to relate grain economics to the environmental history of nitrogen accumulation.

Joan Thirsk attributes fodder innovation to relative labour availability. She writes that while *B. napus* was quietly introduced to a few corners of the English landscape as early as 1255 for trials on monastic sites in east Norfolk, the crop could not spread widely during the plague due its requirement for increased farm labour during a time that pre-dates horse-drawn ploughing innovation. Like turnips, *B. napus* was a labor intensive crop that required hoeing and weeding as well as attention to the rate of application and timing of seeding. By the end of the major epidemic cycle in 1480, these logistics were difficult because plague mortality had reached nearly 50% in many parts of England, greatly limiting the types of crops that could be cultivated at the mass scale. According to Thirsk, "…it is not impossible that [rapeseed] survived quietly in some undiscovered corner of the kingdom in the fifteenth century. But, if so, it has left us no documents."[142]

In contrast, in France and parts of the lower Rhine, where disease casualties were fewer and some areas went unscathed during the plague, a greater labor supply facilitated the continuous cultivation of rapeseed during the fourteenth and fifteenth centuries. This allowed French and Norwegian farmers to develop oil milling technology and integrate rape oil into textile finishing and cloth making practices in place of olive oil or animal lard. Villages entered the early modern period with a craftsman heritage, and many clothiers in France, Germany, and Norway no longer used olive oil at all. Others developed techniques that allowed the two oils to be mixed for textile finishing.[143] When clothier Benedict Webbe was granted patent rights to a

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[141] Ibid., p. 448.
[142] Thirsk, *Alternative Agriculture: A History from the Black Death to the Present Day*, p. 16, 72.
[143] Ibid., p. 73-4.

rape oil mill system that he imported from France in the early seventeenth century, rapeseed spread widely through the kingdom. *B. napus* take up was at first determined by demand, and innovation was supported as a project of the Royal Court. Thus, *B. napus* may have reached the industrial scale in the seventeenth century when it was planted at the scale of 3,200 to 4,000 acres for oil production. In contrast, turnips, clover, sainfoin, and Lucerne were only frequently found in botanical gardens in the late 1600s, and larger scale cultivation was achieved in the following century.[144]

As to what determined the tendency towards pasture conversion to arable during the Middle Ages and the smaller herd sizes, Clark believes it was the high rate of discount of future benefits. This favored corn production because current price fluctuations were more predictable. Grain in the barn had an uncertain future value and livestock would sell for more or less depending on the season. Farmers sacrificed the chance to make money today if they diverted land from grain production to grow fodder to fatten cattle. Thus, beyond meeting self-sufficient needs for meat on the table, the risks associated with livestock husbandry were too great a gamble. Such analysis is also available in primary sources from the period. Jane Haldimand Marcet argued in her 1824 *Conversations on Political Economy* that contemporary farmers feared financial loss when altering the chronological design of a farm towards convertible husbandry. The custom was to respond to yield increases by bringing surplus to market early in the season instead of apportioning excess over the whole year through a more dedicated, strategic design that fed livestock and supported a larger herd for beef, milk, and market.[145] But as Haldimand Marcet emphasized, “in bad seasons there would have been no surplus at all.”[146]

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[144] Ambrosoli, *The Wild and the Sown : Botany and Agriculture in Western Europe, 1350-1850*, p. 281-82.
[145] Jane Marcet, *Conversations on Political Economy, in Which the Elements of That Science Are Familiarly Explained*, (London, Longman, Rees, Orme, Brown and Green, 1827), p. 266-8.
[146] Ibid., p. 267.

This was particularly important in an economy that calculated rents in terms of bushels and determined inflation based on average seasonal yields. In the case of a bad crop, grain was worth more and rents increased. With a good crop, rents stayed the same, but due to competition farmers might have earned less per bushel. One can only imagine how these problems were more paramount in the Medieval Period when food scarcity was also a greater problem and surplus dedicated to livestock threatened the future food supply for the family.

Farm size also increased in the eighteenth century, J. D. Chambers argues that in England the trend towards enclosure gradually increased the number of small farms of less than ten acres through land allotments given to cottagers in exchange for the loss of common land rights. However the size of parcels held by the class of larger land holders only increased beyond 200 acres.[147] In England, horsepower became the backbone of land-based factory production, import substitution, and food supplies, and this was made possible by new fodders and the increased yields per acre per worker attributed to the nitrogen they fixed. As Jane Haldimand Marcet wrote, in her 1817 *Conversations on Political Economy*, under the historical land divisions which limited farms to 100 or 150 acres, "… it would have been almost impracticable to practice convertible husbandry at all."[148]

B. napus contributed a solution in the form of waste conversion. Plantings on moor and marsh increased herd size without altering the acreage dedicated to arable.   If the high opportunity costs were more a problem than soil depletion, then rapeseed offered a particularly unique set of economic advantages in that oil could also be produced after foraging without replanting. As a case in point, drainage engineering represents one of the eighteenth century

[147] J. D. Chambers, "Enclosure and Labour Supply in the Industrial Revolution," *The Economic History Review* 5, no. 3 (1953).
[148] Marcet, *Conversations on Political Economy, in Which the Elements of That Science Are Familiarly Explained*, (London, Longman, Rees, Orme, Brown and Green, 1827), p. 261.

projects of unprecedented landscape-level impacts. Entire lakes and tidal marshes were converted into sandy bowls of poor soil. Rapeseed was critical to these projects. James Adam described in his 1789 *Practical Essays on Agriculture* that when determining the best option for a bog "the most profitable may be to sow it in the autumn with rape, the leaves of which shading the surface in hot weather and rotting in winter contribute greatly to mellow the earth."[149] Adam outlines a plan for converting the bog to pasture when he continues "After the rape is off and the stubble burnt or plowed in, it may be immediately sowed with turnips or planted with cabbages which in the spring may be succeeded with barley and with it the grass feeds from upland pastures and white clover may be sowed and the whole be thus laid down for a lasting meadow."[150] It is important that poor soils were only ready for clover after rapeseed and a burning cycle. The introduction of nitrogen fixing legumes required remediation in the form of a *B. napus* planting. The creation of a permanent grazing pasture in place of a marsh required a hardier fodder for the first planting.

The conversion of marsh to planted acreage demonstrates one of the most important yet neglected forms of convertible husbandry in the period. While Allen assumes a traditional convertible husbandry model, many examples in the period literature exceed the simple rotation of arable and pasture by incorporating planted fallow, winter series in arable, or the conversion of waste. For example, in 1798 Clement Archer recommended a similar strategy for draining peat moss and bogs when he wrote:

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[149] Adam, *Practical Essays on Agriculture : Containing an Account of Soils, and the Manner of Correcting Them. An Account of the Culture of All Field Plants. Also, an Account of the Culture and Management of Grass-Lands; Together with Observations on Enclosures, Fences, Farms, and Farmhouses, &C. Carefully Collected and Digested from the Most Eminent Authors, with Experimental Remarks*, 1, p. 72.
[150] Ibid., p. 71-2.

> After draining and working the surface either with the plough or spade it will even in the first season reward the husbandman pretty amply for his trouble with a *good crop of rape*. The next year after the lime stone gravel has been drawn out on it or that it has been marled limed or covered with mould it will produce most abundant crops of oats or other grain and after that when laid down with grass feed it becomes the richest and most luxuriant meadow land in the world.[151]

Here again rapeseed served as a vehicle for expanding net productivity in that it transitioned bogs and marshes that might have only supported a few wandering, grazing sheep into planted fodder that fed an entire herd. Thus, as the preference for more arable versus more grazing shifted with time, convertible husbandry tools and techniques altered the percent distribution of landuse types. In fact, it was not that the introduction of new fodders saved the day, but rather that farmers developed the techniques needed to strategically scale plant technologies to this larger level so that on any site marsh conversion might be combined with green fallowing, winter feed plantings, and perhaps a rotation of permanent pasture with arable over time.

Rapeseed was particularly useful when implementing convertible husbandry designs at the regional landscape scale. For example, Colonel William Fullarton used estimates of acreage published by Arthur Young to detail the increased productivity that would come from the convertible tillage of one-third to one-fourth of the 1,300,000 unproductive grazing acres in Cheshire and Leicester. He boasted "it is obvious that the average produce would be more than double, in many cases triple, the produce of ordinary cultivated lands in England." Here the predicted increase was due to the conversion of manured land that had been long grazed, yet had become unproductive due to over grazing or under use. Though Fullarton was boasting for the sake of persuasion, such acreage promised to successfully support crops with tillage, marling,

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[151] Clement Archer, *Miscellaneous Observations on the Effects of Oxygen on the Animal and Vegetable Systems; ... And an Attempt to Prove Why Some Plants Are Evergreen and Others Deciduous, in the Climate of Great-Britain and Ireland*, vol. 1 (Bath: printed by R. Cruttwell; and sold by C. Dilly, London; Gilbert, Dublin, 1798), p. 71.

and regenerative plantings. Fullarton listed rapeseed as one of the essential plants used in series after the tillage of pasture for conversion to arable. He believed this would allow the entire Kingdom to add seven to ten millions of quarters of grain to the national supply in just one short year, added Fullerton.[152] In 1813, Thomas Batchelor similarly published a second edition of the *General View of the Agriculture of the County of Bedford* and confirmed that coleseed technologies were becoming all the more important for larger-scale plantings that replaced meadow and pasture with fodder.[153] Based on the additional years of observation since the 1794 printing of the work, Batchelor wrote that farmers made the same profit in three years of wheat rotations as in the prior 30 years of meadow or pasture thanks to the integration of coleseed and animal husbandry into a grain course.[154] Thus, from the many examples of landscape-level reclamation with *B. napus*, it is clear that nitrogen cycling is only part of the story.

Over time, alternative fodders like rapeseed and turnips increased the value of future crops by ensuring a stable and robust agricultural system capable of supporting more livestock while simultaneously increasingly grain yields. The modifiable nature of convertible designs allowed farmers to exploit the multiple functions of alternative fodders like *B. napus*, which were used to re-organize land use types at a greater spatial scale than was before possible without organized labor, such as manorial serfdom or plantation slavery. We can estimate a larger benefit from fodder projects that included rapeseed, which diversified soil contributions.

Returning to the eighteenth century and the question of the chronology of the British Agricultural Revolution, it is also clear that integrative design schematics became more

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[152] Colonel Fullarton, *A Letter, Addressed to the Right Hon. Lord Carrington, President of the Board of Agriculture*, Goldsmiths'-Kress Library of Economic Literature ; (London: Printed for J. Debrett, 1801), p. 9.
[153] Thomas Batchelor, *General View of the Agriculture of the County of Bedford. Drawn up for the Consideration of the Board of Agriculture and Internal Improvement*, ed. Agriculture Great Britain. Board of and Thomas Batchelor (London: Printed for Sherwood, Neely and Jones, 1813), p. 232, 354, 418, 23.
[154] Ibid., p. 245.

diversified and efficient through the combining of *B. napus* and *B. rapa subsp. rapa*. Regardless of the relative sophistication of continental technologies or the chronological comparisons with seventeenth century tools, it is clear that designs that harnessed new fodders for convertible husbandry grew to a larger scale in the late eighteenth century. By the end of the long eighteenth century, it became more common to maintain both grazing and arable on the same farm to support larger herd sizes. For example, in *An Account of the Systems of Husbandry Adopted in the More Improved Districts of Scotland*, Sinclair wrote:

> On the whole, the convertible system of husbandry, where one-half of a farm is in grain, and the other half in grass and green crops, is in general to be recommended. By the grain crops, a sufficient quantity of straw is provided as food for cattle, where that mode of feeding is adopted, or for being converted into dung, in addition to a reasonable profit to be derived from the grain.[155]

This quote is helpful for demonstrating ratios to describe the ideal distribution of land use types on a farm. Archibald Cochrane, Earl of Dundonald, similarly praised practices in Scotland for tilting relative ratios towards grasses in *A Treatise, Shewing the Intimate Connection that Subsists Between Agriculture and Chemistry*. He wrote:

> The convertible husbandry, or the management of farms in an alternate course of tillage and pasture, is in general well understood in the highly cultivated parts of Scotland, from which system the crops of artificial grasses are infinitely more abundant than from any mode of cultivation in England.[156]

This illustrates the tendency of eighteenth century period actors to scale convertible husbandry to the landscape level and describe land patterns in spatial terminology. By defining convertible

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[155] John Sinclair, *An Account of the Systems of Husbandry Adopted in the More Improved Districts of Scotland; with Some Observations on the Improvements of Which They Are Susceptible. Drawn up for the Consideration of the Board of Agriculture with a View of Explaining How Far Those Systems Are Applicable to the Less Cultivated Parts in England and Scotland*, ed. Agriculture Great Britain. Board of, The 3d ed. ... ed., 2 vols., vol. 1 (Edinburgh: A. Constable, 1814), p. 342.

[156]Archibald Cochrane, Earl of Dundonald, *A Treatise, Shewing the Intimate Connection That Subsists between Agriculture and Chemistry, Addressed to the Cultivators of the Soil, to the Proprietors of Fens and Mosses, in Great Britain and Ireland; and to the Proprietors of West India Estates* (London: J. Murray and S. Highley, 1795), p. 105-6.

husbandry according to this shift in the spatial composition of a farm, we broaden the more common textbook definitions to reflect period accounts of real practices.

In conclusion, latent in these examples is a reciprocal co-determination between the environmental design of convertible husbandry and the technological innovation illustrated by fodder combinations. Fodder technology innovation may have stagnated during the late seventeenth century and early eighteenth century introduction in part because farmers lacked the spatial and temporal strategies to integrate a diversity of new crops into the productive cycle with livestock. We cannot dismiss the importance of new fodders like *B. napus* and turnips to the sustained increases in herds and the many subsequent benefits to the soil that far exceeded nitrogen inputs. But it was ultimately the integration of multiple existing components into a litany of diverse functional systems that supported larger herd sizes and set in place a new feedback loop—the increase of manure for better fodder and crop planting, which supported larger herds and greater manure inputs.

This is why Robson ends his essay by likening turnips to guano. “If Grosvenor’s mines had been as rich as those of Peru, they could not have done so much for England and the English people as Townshend’s turnips,” he wrote.[157] By referencing a line in Alexander Pope’s poem *Imitations of Horace, Epistle II*: “All Townshend’s turnips, and all Grosvenor’s mines;” Robson suggested that if lead mines held by Sir Thomas Grosvenor had instead produced the silver found in Peru, the benefits to the soil and economy would never surpass those made by turnips. Robson attributes the discovery of turnips to Charles Townshend, who implemented field turnip agriculture at his estate in Raynham, Norfolk in the 1730s. Yet just as Kerridge outlines a much earlier introduction of the crop from the continent and a subsequent evolution of field practices

[157] Robson, "Turnip Husbandry," p. 102.

over many generations, my work illustrates that *B. napus* was innovatively integrated into growing systems through site-specific designs following an early seventeenth century introduction. Turnips were most successful when combined with *B. napus* and other crops, and far from a revolutionary take-off, this agrarian transformation gradually evolved as plant technologies introduced in the seventeenth century were innovatively integrated into site-specific agronomical designs. More than the introduction, dispersal, and adoption, the story of *B. napus* combining with turnips may be a better indicator of reliable crop yields, land efficiency, and the robust nature of the modernizing agricultural landscape.

CHAPTER FOUR: Rapeseed in the Norfolk Rotation for Course Design Diversification

I. Introduction

The 1945 film *Make Fruitful the Land* documents the history of the Norfolk Four Course Rotation with the help of vintage animation, live farm footage, and the sort of theatrical music that sounds like someone is about to save the day. Archived by the British Council, the documentary celebrates the Norfolk as a cornerstone of modern agriculture. In the first year of a Norfolk Rotation, cartoons of wheat appear in the field, while in the second year, turnips spring to the stage. This is followed by barley and clover in the third and fourth years. Each crop takes the spotlight as the music slowly gains volume and tempo to build suspense. Then enters our grand hero—a plan of four fields where each crop cycles through one quadrant during a growing season. "In this way, each crop helped to provide the right conditions for the growth of the crop which followed it," says our narrator.[1] While wheat served as the cash crop, it was the rest of the Norfolk Rotation that made ongoing production possible. "The clover crops then restored the fertility that the grain crops had taken out of the soil," he says.[2]

This classic model has long been referenced as a defining example of agricultural improvement and a cornerstone of the British Agricultural Revolution. Mrs. A. M. W. Stirling even writes of the Norfolk as if it were an agricultural saga staring Thomas William Coke, who some historians have credited with the innovation of the four course rotation.[3] Stirling portrays Coke's innovation as rapid but the test of persuading the ignorant locals as an art of stalwart

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[1] Ken Annakin, "Make Fruitful the Land " (United Kingdom 1945), 6 min.
[2] Ibid., 4 min 30 sec to 6 min 30 sec.
[3] A.M.W. Stirling, *Coke of Norfolk and His Friends: The Life of Thomas William Coke, First Earl of Leicester of Holkham, Containing an Account of His Ancestry, Surroundings, Public Services & Private Friendships, & Including Many Unpublished Letters from Noted Men of His Day, English and American* (Lane, 1912), p. 172-8. .

heroism. She quotes W. A. Dutt's *Highways and Byways in East Anglia* when she writes "The life-story of 'Coke of Norfolk' is too much made up of agricultural technicalities to be generally attractive, but to the Norfolk farmer, it reads like a romance—an agricultural romance."[4] The Norfolk is historically significant for increasing soil nitrogen fixation through its incorporation of clover, for integrating livestock traditionally kept in common pastures into arable acres via grazing of clover, and for sustaining repeated cycles of soil depleting crops like wheat. In his book the *Agricultural Revolution in England,* Mark Overton describes a long lag time between the introduction of clover, turnips, and the other leguminous grasses used in The Norfolk and the development of the system of rotation.[5] "Nevertheless, there can be no doubt of the superiority of the new system at whose root quite literally lay the improved management of soil nitrogen," writes Overton.[6]

Due to the popularity of the nitrogen thesis, historians most commonly associate the Norfolk with the disbursal of clover—a common name for many different species in the family Fabaceae that fix nitrogen. Yet a more careful study of course design shows that alternative fodders were also used in rotation, and by considering the range of designs, new improvement mechanisms emerge from the late eighteenth and early nineteenth century archives. For example, while *B. Napus* has so far been excluded from studies of rotation, it appears frequently in the courses of wheat, barley, oats, turnips, and clover planted for soil improvement. Examples of the integration of *B. napus* into the course rotations combined with pairing and burning suggest that period actors knowingly harnessed pathogen suppression mechanisms. The frequent

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[4] Ibid., p. 173; William A. Dutt and Joseph Pennell, *Highways and Byways in East Anglia*, The Highways and Byways Series (London, New York: Macmillian and co., limited, 1901), p. 234.
[5] Mark Overton, *Agricultural Revolution in England : The Transformation of the Agrarian Economy, 1500-1850*, Cambridge Studies in Historical Geography. (Cambridge ; New York: Cambridge University Press, 1996), p. 120.
[6] Ibid., p. 120.

use of *Brassica napus* (*B. napus*) in courses that otherwise adhere to the traditional crops of a proper Norfolk Rotation suggests that the quintessential model was the exception rather than the norm. Finally, *B. napus* can also be traced through longer and more diverse courses that use a variety of other crops, which demonstrates how farmers cultivated malleable designs to meet the site-specific demands of environmental conditions. Mechanical technologies and crop introductions may have streamlined planting practices, but late eighteenth century designs also solved the pragmatic problem of site-specific implementation under variable and diverse environmental conditions through temporal diversification and the use of alternative species.

Though it is very rare to find logs that document the crops planted over many years in the same field, 1808 records from Mr. Thornton of Burstwick Garth held at the Treasure House in the East Riding of Yorkshire document a proper Norfolk that includes rapeseed. While projecting his tithe rent over future years from past planting successes, Thornton recommended that either turnips or rape could be grown interchangeably as part of the rotation. "These must be taken in a yearly average of 15 acres fallow, 15 acres spring corn, 15 clover, & 15 wheat. The fallow to be Rape or Turnips," he writes. "If the fallow is a dry one then there will be 2 crops of wheat in the four course which will bring the amount to equal the above."[7] Such a course was essential to maintain soil fertility the East Riding geography characterized by chalky cliffs and lowlands, and especially in Burstwick where soils and subsoils consist of clay, sand, and gravel.[8] Mid-to-late eighteenth century farmers describe the transition of bare to planted fallows to graze animals, support larger herds, and provide greater manure inputs all without increasing acreage. Sometimes green fallows of rape or clover replace the bare fallows of uncovered soils thought to

[7] "Memoranda and Details of Crops on Mrs Thornton's Estate in Burstwick (Burstwick Garth)," (East Riding Archives, Beverley Treasure House 1808-1815).
[8] GENUKI, "Burstwick: Geographical and Historical Information from the Year 1892.," https://www.genuki.org.uk/big/eng/YKS/ERY/Burstwick/Burstwick92.

regenerate the earth through exposure to rain and air. Though the modern concepts of biochemical and microbial mechanisms were unknown, rape and clover were thought nourishing for soils. As the Norfolk Rotation arose from the integration of new fodders for grazing into arable acres, it is perhaps no surprise that alternatives like rape found their way into the cycle.

While the textbook example of clover, turnips, wheat, and barley are memorialized as the Norfolk Four Course Rotation, the few historians who tackle the evasive archives of cultivation tables, farm inventories, and regional crop experts confirm a more complex history if innovation and least some diversity in implementation. Naomi Riches dedicates two sections in *The Agricultural Revolution in Norfolk* to the development of course rotation and its economic impacts. Her evidence shows that Coke was not the first inventor and demonstrates the contributions of numerous farmers made over centuries.[9] While the chronologies of first adoption and widespread use remain debatable, Riches argues that the four-course crop rotation was perfected in the Norfolk much earlier than Overton suggests, and though she holds the proper rotation as a model, her examples demonstrate significantly more crop diversity. "Of course, scientific crop rotation would not be possible without the introduction of clover, turnips, and the artificial grasses," writes Riches.[10] Yet at Sandringham, farmers planted turnips, barley, clover and ray grass for two years before a cash crop of wheat. At Snettisham "a fallow year was followed by wheat, barley, turnips, clover for two years, then wheat." This last cycle only introduced the fallow once in eight years, but is controversial as an example of the Norfolk for planting barley directly after wheat and for raising wheat in two successive crops without regeneration.[11] "Variations might be multiplied, but these few illustrations serve to show what is

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[9] Naomi Riches, *The Agricultural Revolution in Norfolk*, 2nd ed. with a new bibliographical note by W.W. Chaloner. ed. (London: Cass, 1967), p. 81-3.
[10] Ibid., p. 82.
[11] Ibid., p. 82-83.

meant by the Norfolk system of crop rotation," writes Riches, who cites far fewer examples of a proper Norfolk Rotation.[12] For example, "Mr. Carr at Massingham planted turnips, barley or oats, clover, wheat," even while the majority of her cited farmers were less cliché.[13] Yet while it is not uncommon to find alternative grasses like sainfoin or Lucerne used along with or in place of clover, and while the secondary sources account for oats and rye in the Norfolk rotation, Riches offers no examples of rotations that harness *B. napus*. Though the primary sources that Riches quotes show that rape was used as a fodder for sheep along with turnips as early as 1669, and though her export logs from the end of the eighteenth century show that rape was grown in surplus along with wheat, beans, peas, and rye, her cursory review of the Norfolk Rotation does not highlight alternative the frequent use of alternative crops in course design.[14]

If we dig so deeply in the archives at to uncover planting records that illustrate the Norfolk, it turns out that rotations of clover, barley, turnips, and wheat often incorporate rapeseed. In a rare pile of late eighteenth and early nineteenth century cultivation tables recorded in Boynton and Carnaby, Charlston in the East Riding of Yorkshire lies a detailed record of a Norfolk Rotation with rape used between plantings of wheat.[15] Let by William Simpson, the property was divided into 19 numbered fields with each crop documented from 1828 to 1837. A corresponding sketch outlines the orientation of the plots. Though rape was not used in every field, it is the only alternative crop that stands out from the regular courses of turnips, wheat, oats, and various grasses such as sainfoin or clover. Occasionally barley is substituted for oats, and peas are used an alternative legume. Seed plantings are also incorporated on some plots.

[12] Ibid., p. 83.
[13] Ibid.
[14] Ibid., p. 84, Riches references John Worlidge's Systema Agriculturae; Export logs can be found on 147-52.
[15] "Cultivation Tables at Boynton and Carnaby, Charlston," (East Riding Archives, Beverley Treasure House 1828-1840).

Yet in each of the 19 fields, a proper Norfolk Rotation is implemented over nine years with very little derivation besides the inclusion of *B. napus* in "Plot 2." This example shows the importance of rapeseed on a wide range of soils as Carnaby and much of Boynton are characterized by a mixture of loam and clay with subsoils of chalk and clay.[16] This contrasts to the chalk, sand, and gravel common in other parts of the East Riding.

Simpson's design confronts us with an intriguing puzzle: why did he integrate rapeseed? The crop may have been used to extend the fecundity of the soil for an additional planting of cash crop. The *B. napus* planting is preceded and followed by wheat.[17] Yet wheat is never again repeated in two consecutive years. Even in the case of the rape crop, the preceding planting intermixes wheat and oats. Since many period inventories focus on valuations and at best list planted crops, it is rare to find such a detailed chronological schematic. However this example is also unique for including a spatial arrangement of plots. Marginalia in the form of faded notes and numbers suggest that this table and drawing integrate pragmatic designs for real use rather than for display or presentation. We gain from the scratches of arithmetic and fragmented sentences a sense of strategy in the works. The table outlines low intensity rotations in which grass is planted for two or three years followed by turnips, likely for grazing, before the taxing cash crop of wheat is followed by oats or barley. Rape seems to have been strategically harnessed to break apart a wheat crop, however from this evidence alone we can say little of whether the design succeeded or failed.

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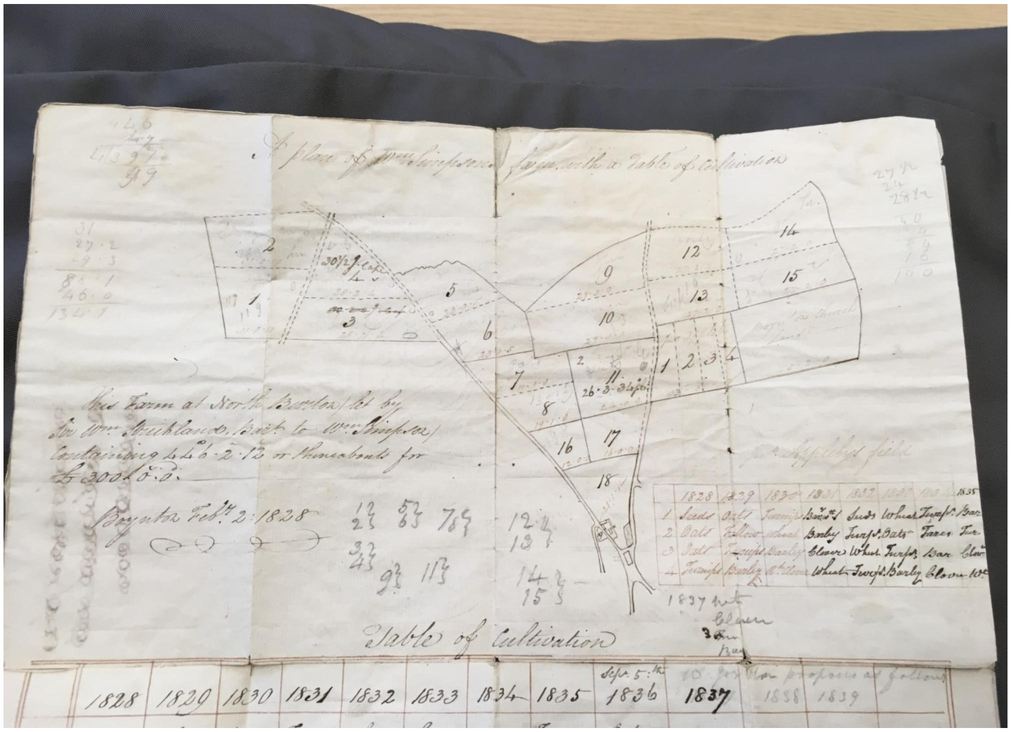
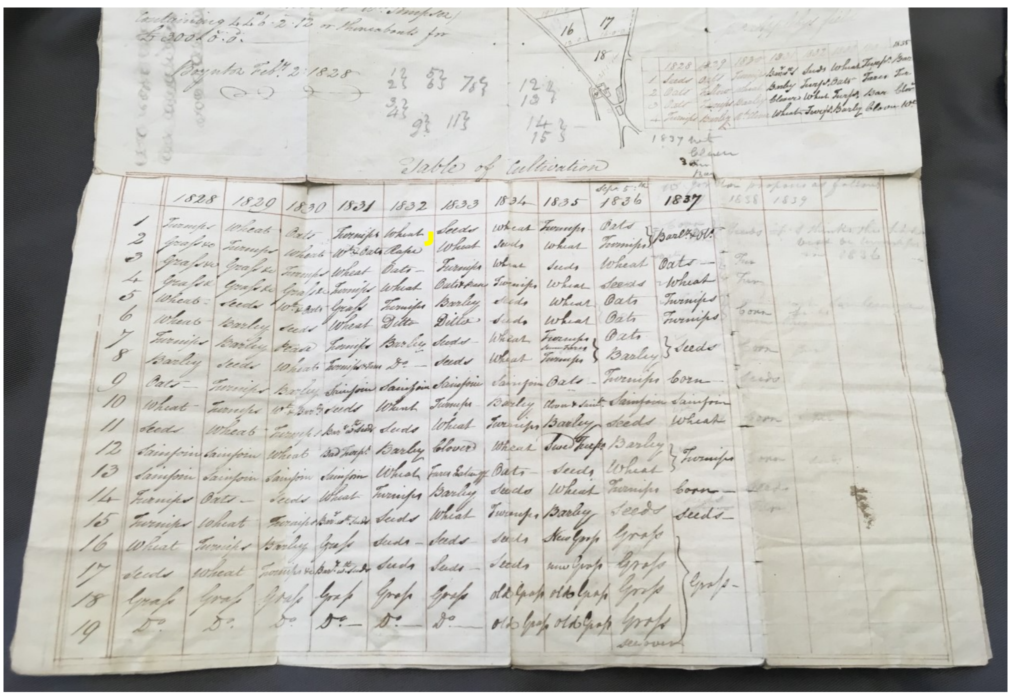
[16] GENUKI, "Carnaby: Geographical and Historical Information from the Year 1892.," https://www.genuki.org.uk/big/eng/YKS/ERY/Carnaby/Carnaby92.
[17] "Cultivation Tables at Boynton and Carnaby, Charlston."





4.1 *Planting Calendar from the East Riding of Yorkshire, 1828 to 1837***.** Reproduced with courtesy of the Stricklands of Boynton Hall Family and Estate. This rare planting calendar recorded by a tenant farmer named William Simpson in Boynton and Carnaby, Charlston is rare for detailing the spatial arrangement of rotations by plot number and for including the crops planted in a 10 year course in 19 different fields. Rapeseed (highlighted in yellow) is included in the second plot in 1832 as part of a Norfolk Rotation.[18]

[18] Ibid.

Some might argue that if a species like rape is integrated, the planting design is not a proper "Norfolk Rotation." Perhaps such modified patterns should be called something else. To the contrary, Simpson's use of *B. napus* in a design that otherwise replicates the quintessential Norfolk Rotation demonstrates that the design was implemented according to the interests of the farmer and their plan for the land. *B. napus* is a sign of design modification because it appears in rotations that otherwise replicate the definitive series of grass, wheat, turnips, and barley or oats. Regardless of whether dramatic derivations are more abundant than the classic examples in the archives, the proper Norfolk is more than an imaginary developed by modern readers who look backwards at ages of innovation to reconstruct the minutia of the past. To the contrary, the Norfolk Rotation does exist as a period design and it sometimes includes *B. napus*.

Rape is more frequent in other cultivation tables from the East Riding estates, where I enjoyed the longest visit of any of my trips to the archives due to the historical importance of rapeseed crushing in the county.[19] In the *History of Seed Crushing in Great Britain*, Harold Brace attempts to list all oilseed mills in England and Scotland in production in the eighteenth and nineteenth centuries. His inventory of more than 600 sites shows a cluster in the East Riding of Yorkshire, where there were about 20 mills in operation. In contrast there was only one mill documented in all of Sussex. Depending on the time of survey collection, there were fewer than about 85 counties in England, Scotland and Wales in the nineteenth century, and most supported fewer than five mills.[20] Rape was not the only oilseed crushed at the mills, which were also used to make bone meal and other manures. But the likely centralization of oilseed crushing on the eastern coast of England combined with the rich soils in the Vale of York positioned the ports in

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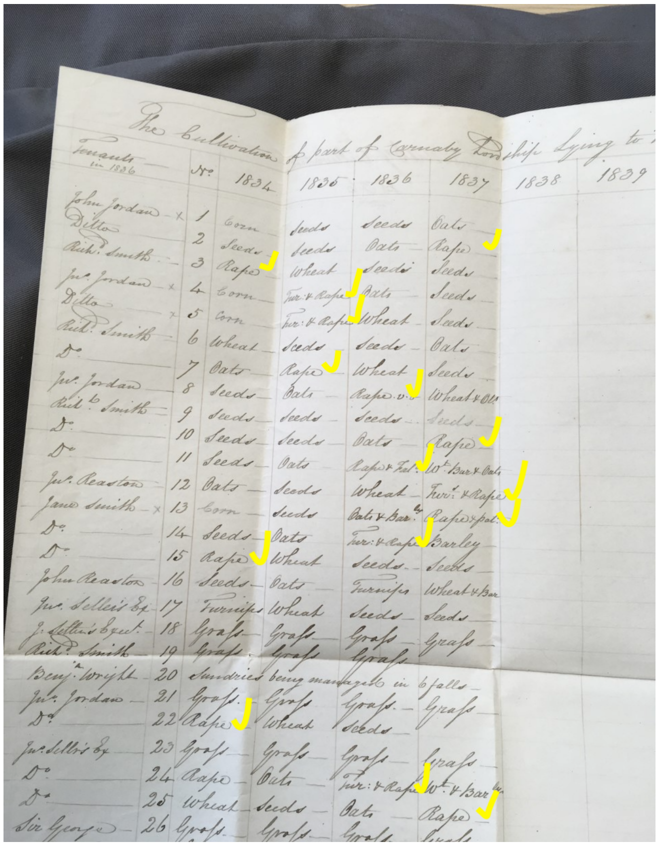
[19] Harold Witty Autor Brace, *History of Seed Crushing in Great Britain / Harold W. Brace* (London: Land Books Limited, 1960), Book. See list of more than 600 seed crushing mills by alphabetical listing. The East Riding of Yorkshire has some of the most mills.
[20] Ibid., p. 99-167, Appendix A.

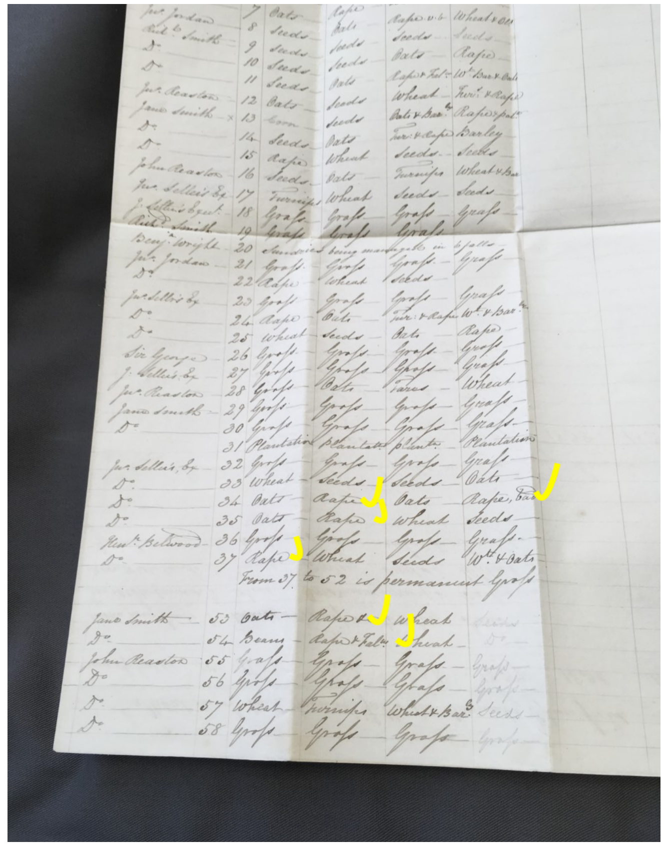
Kingston upon Hull to become a nexus for seed imports from continental Europe as well as a location where oilseed was grown to feed the mills. Though examples of the Norfolk Rotation are rare, I hoped that proof of rapeseed in rotation would more likely in the East Riding of Yorkshire archives than in geographies that historically supported fewer mills.

In most other examples, the classic Norfolk crops are planted as incomplete cycles consisting of a series—a progression of certain crops that prepares the soil for a cash crop planting, but falls short of a full course. In the same file where Simpson's cultivation tables were discovered, I found lists of crops growing in local fields.[21] Rape appears in more than half of the series planted on about 30 different fields between 1834 and 1837. It is most often planted before wheat, oats, or barley, though it is sometimes mixed with turnips. None of the series plantings include all of the Norfolk crops in a perfect chronology, however the farmers exclusively use the typical Norfolk crops of wheat, oats, barley, turnips, and grass. Here *B. napus* reflects an integration of the crop into the regional improvements practiced by many different farmers. Along with the ambiguous category of "seeds," no other alternatives to the Norfolk crops are planted. In contrast, tithe surveys and probate inventories often show a much greater diversity of crops including carrots, onions, swedes, beets, potatoes, woad, flax, vetches, peas, beans, and tobacco, just to name a few.

It is unlikely that rape found its way into the East Riding designs by chance because the plan appears on multiple properties subdivided into wide range of complex and simple spatial designs. In this same file that contains the more sophisticated depictions of arrangements Simpson's land, we also see drawings of rape designs that subdivide plots int more simple rows.[22] In a beautiful drawing of the fields belonging to George Riby, we see rape planted with

[21] "Cultivation Tables at Boynton and Carnaby, Charlston."
[22] Ibid.





4.2 *Planting Calendar from the East Riding of Yorkshire, 1834 to 1837.* Reproduced with courtesy of the Stricklands of Boynton Hall Family and Estate. This second planting calendar from the William Simpson file documents the four year courses implemented on multiple farms in the area. Rapeseed (highlighted in yellow) is included in nearly nineteen different courses, which shows its integration into the local rotation system.[23]

[23] Ibid.

turnips in a six course design. The field is divided into two rows of four planted plots. The bottom rows designated “A, B, C, D” appear to have been sequentially planted from 1835 to 1840.[24] Here the pattern rotates the same crops used in the traditional Norfolk but sometimes plants wheat after the turnips and followed by clover and oats. Two course designs planted in the top rows numbered one to four also integrated rapeseed.

One final example dates to the late eighteenth century and similarly shows evidence of a rape series that includes the classic Norfolk crops. A quantity valuation letter from December 14, 1789 outlines the crops growing on farms at the Willerby Estate near Hull in the East Riding of Yorkshire.[25] In this discovery, rape is integrated into multiple field courses of wheat, turnips, barley, and clover planted by a farmer named Thomas Frank from 1786 to 1793.[26] While a perfect Norfolk Rotation of barley, wheat, turnips, clover, turnips, and turnips is documented on a plot descriptively located south of Malton Road, we see rape integration into series of oats, barley, and wheat at the Franks Tillage on Willerby Wold. Here rape is sometimes mixed with turnips and planted between repeated crops of oats.

Such findings offer only anecdotal evidence of the Norfolk Rotation; we can only infer the role of *B. napus* in improvement from its inclusion in a list of crops. As the authors left tables and valuations in place of descriptions of goals, we can only evaluate the crops and rotation patterns through the lens of a modern historiography that values the Norfolk Rotation as a defining example of agricultural improvement. Though *B. napus* is frequently incorporated into designs that are clearly strategic in their formation, we can only guess that the crop was used

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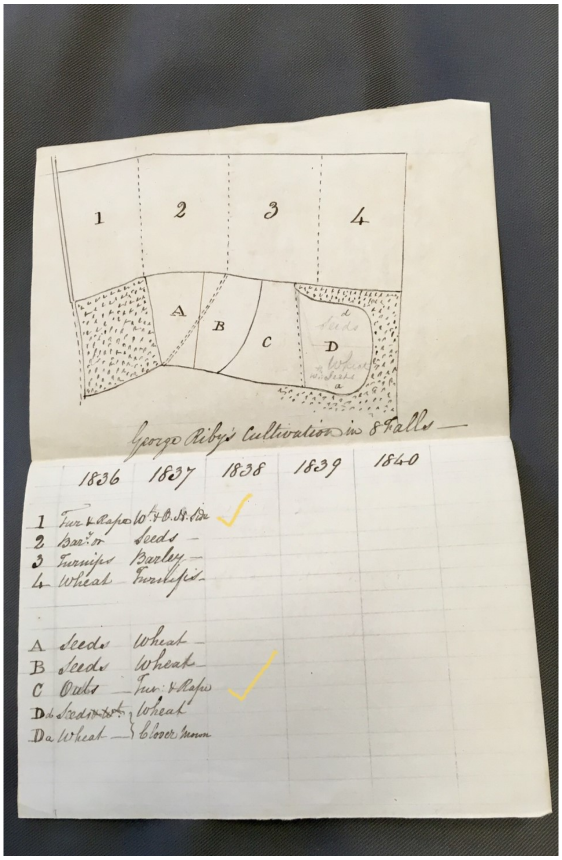
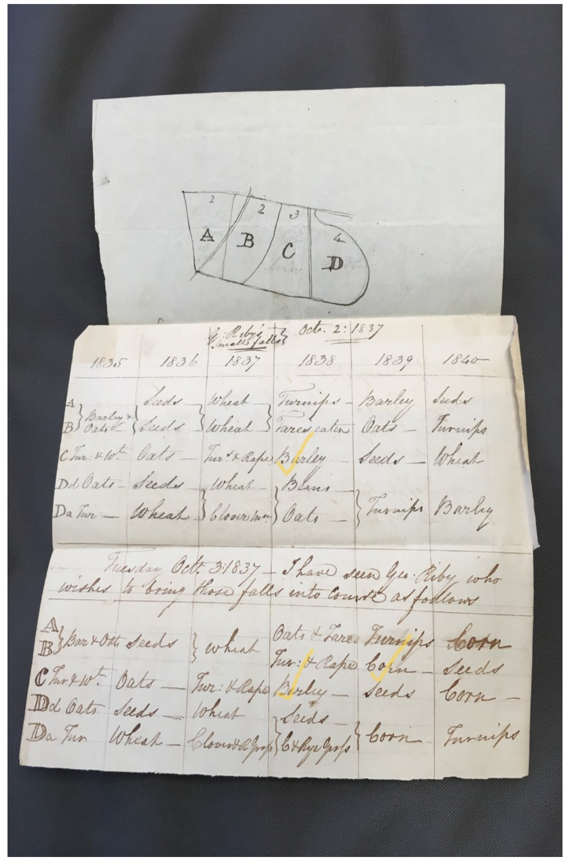
[24] Ibid.
[25] "An Account of the Quantity, Valuation and Total Amount of a Crop of Corn at Willerby, the Property of Thos. Frank Valued to Rt. Broadley Esq.," (East Riding Archives, Beverley Treasure House 1790).
[26] Ibid.





4.3 *Planting Calendars from the East Riding of Yorkshire, 1835 to 1840.* Reproduced with courtesy of the Stricklands of Boynton Hall Family and Estate. Rapeseed is integrated into turnip plantings as part of a course rotation.[27]

[27] "Cultivation Tables at Boynton and Carnaby, Charlston."

in place of turnips as fodder to increase manure contributions or perhaps as a green fallow to regenerate the soil.

Yet the rare planting tables noted in this chapter represent a new kind of evidence hitherto neglected by other scholars of the Norfolk Rotation. There is surprisingly little peer-reviewed academic literature on the Norfolk Rotation that evaluates primary source evidence of field management because planting logs are rare in any form. Unlike account books, probate inventories of farms, and tithe surveys, cultivation tables and planting logs were often scribbled for benefit of the farmer or his or her planting labour. They were hastily written on poor quality paper, abused during use, and rarely preserved for future generations because they were intended for practical purposes. In addition, most period inventories are limited by temporality; surveys of fields and barns are either conducted during the spring planting season or during the fall harvest season, but rarely do methods repeat the same inventory on the same site during both growing seasons. Few documents illustrate all crops grown in a year, much less over multiple years. This is a major problem because clover and grasses were commonly seeded in the spring or summer, while turnips were planted through the later summer for a fall or early winter harvest. Thus, it is rare that a survey of barrels in the barn or crops in the field shows all components of the Norfolk Rotation. Though the Norfolk is frequently referenced in period improvement manuals, it is difficult to find proof of its material existence in period manuscripts.

Most famously, Mark Overton turned to probate inventories in Norfolk and Suffolk but was unable to show widespread adoption of the full rotation even in the very counties where the technology was thought to have been first widely adopted.[28] Probate inventories conducted

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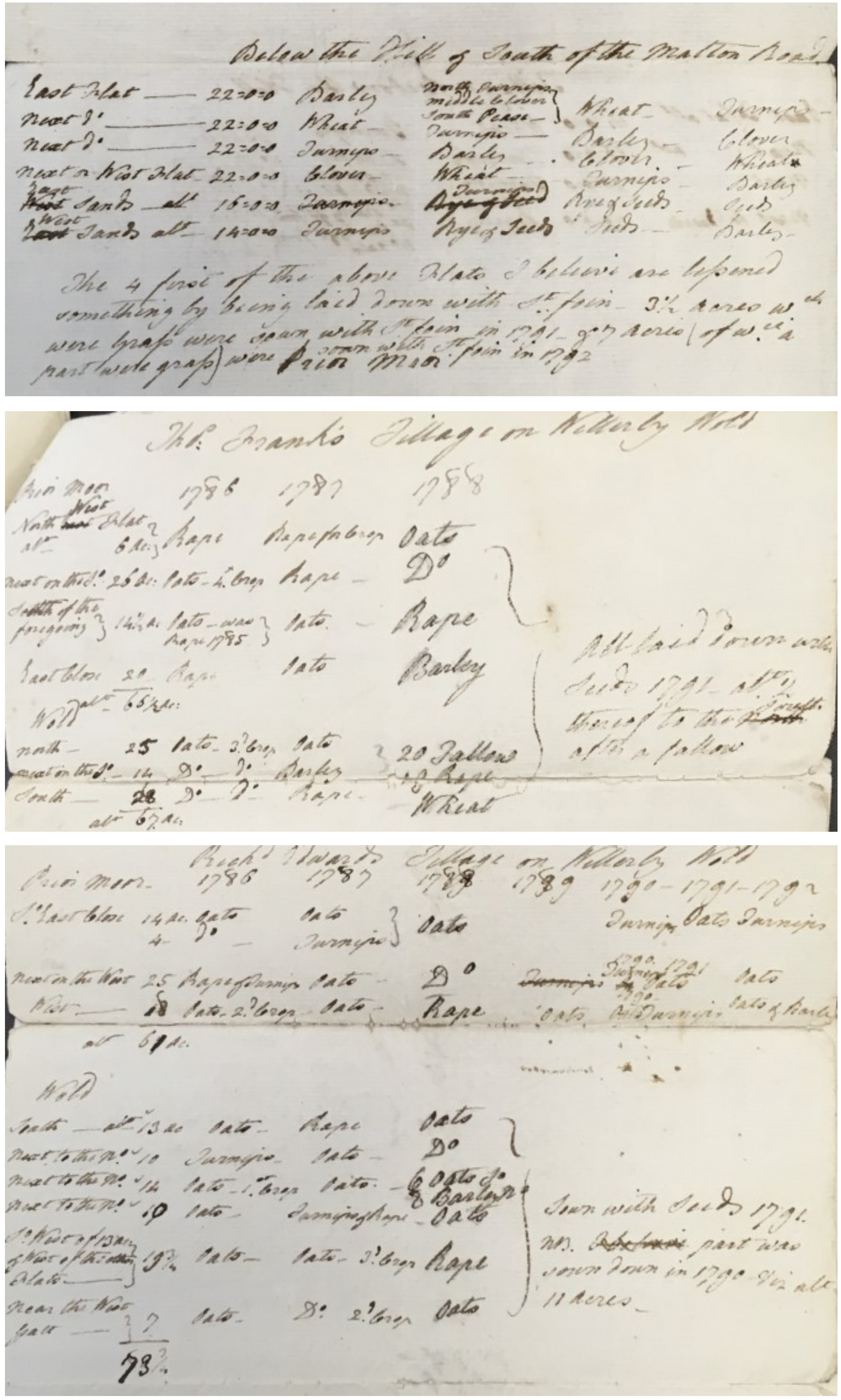
[28] Mark Overton, "The Diffusion of Agricultural Innovations in Early Modern England: Turnips and Clover in Norfolk and Suffolk, 1580-1740," *Transactions of the Institute of British Geographers* 10, no. 2 (1985).



Below the Hill & South of the Malton Road

East Flat — 22:0:0 Barley
next D° — 22:0:0 Wheat
next D° — 22:0:0 Turnips
next & West Flat 22:0:0 Clover
East Lands abt 16:0:0 Turnips
West Lands abt 14:0:0 Turnips

The 4 first of the above Flats I believe are lessened something by being laid down with St. foin. 3½ acres w.ch were grass were sown with St. foin in 1791 — & 7 acres (of w.ch a part were grass) were sown with St. foin in 1792 Prior Moor

Thos. Frank's Tillage on Willerby Wold

Prior Moor 1786 1787 1788
North West Flat abt 6 ac. Rape Oats
next on the S.o 25 ac. Oats Rape D°
East Close 20 Rape Oats Barley
Wold abt 65½ ac.
North 25 Oats Oats 20 Fallow & Rape
South 28 D° D° Rape Wheat
abt 67 ac.
All laid down with Seeds 1791

Tillage on Willerby Wold
Prior Moor 1786 1787 1788 1789 1790 1791 1792
Wold
Sown with Seeds 1791.

4.4 *Planting Calendar from the East Riding of Yorkshire, 1786 to 1789*. Reproduced with courtesy of the East Riding Archives. This planting calendar shows the crops grown on the Willerby Estate by Thomas Frank. Rape is integrated into field courses of wheat, turnips, barley, and clover.[29]

[29] "An Account of the Quantity, Valuation and Total Amount of a Crop of Corn at Willerby, the Property of Thos. Frank Valued to Rt. Broadley Esq.."

when a farmer died by members of the church often list moveable belongings important to the execution of wills and payments of debts or taxes. Though probate inventories do not usually include fodder crops planted in meadows, they often note the amount of grain stored in the barn as well as any cash crops planted in the fields. In a stunning display of paleographic skill, Overton surveyed more than 4,000 probate inventories collected between 1590 and 1740 for root crops such as turnips, carrots, and onions, and for grass substitutes like clover.[30] He also noted inventories of carts and wagons, as these were needed to move turnips from the field for storage.[31] To survey grasses, Overton focused only on inventories made between March and July, and to study root crops, he surveyed those inventories taken during the harvest season of August to December.[32] By 1740 root crops were inventoried on more than 50% of farms. This contrasts to the 1670s to 90s when roots were grown or stored on five to 20% of farms. Clover was generally less documented, but followed a similar course of increase from about zero to 20% prevalence. Both crops were grown on less than one acre per farm at the beginning of the study period, but increased to about one to two acres for clover and four acres for turnips.[33] It is clear that each of the components of the Norfolk Rotation were becoming rapidly more abundant by the middle of the eighteenth century. Wheat, oats, and barley had long been grown in the area, and turnips and clover completed the list.

Yet despite these promising findings, we cannot conclude that the full Norfolk Rotation was executed on any given farm surveyed for probate, nor can we make assumptions about the diffusion of the Norfolk Rotation into a large number of acres within the counties. Due to the

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[30] Overton, "The Diffusion of Agricultural Innovations in Early Modern England: Turnips and Clover in Norfolk and Suffolk, 1580-1740," p. 205.
[31] Ibid., p. 212.
[32] Ibid., p. 208.
[33] Ibid., Figure 1, p. 208.

limitations of probate archives, Overton fails to show multiple components of the Norfolk on the same farm. This is because probate inventories were rarely if ever conducted on the same acreage in both the spring and fall. For such a circumstance to take place, there would have been two deaths of head of household within a short period.[34] Such a rare case study would at best be anecdotal; a more robust analysis requires statistical analysis of many inventories within the county. Yet probate inventories position crops in place, time, and geography while offering little information about the ways that new crop introductions were harnessed and implemented by local farmers.

Overton attempts to overcome this problem by overlaying geographic disbursal maps of root crops and grass substitutes over time. Such maps indicate a far greater number of technology adopters by the 1715 to 1724 time period. Like clover and root crops, wagons or carts are more common in the northern regions of the counties. As Overton writes "…turnips and clover had several roles to play in the extension of the arable area. Both crops provided a higher yielding source of fodder if they replaced permanent pasture or a weedy fallow. Turnips were also important as a means to the reclamation of light land."[35] However this temporal study of density of abundance of technology adoption does not prove that all three components were integrated into the Norfolk production cycle; Overton does not claim that turnips and clover were grown in rotation with cereals like wheat, barley, and oats.

As to the role of *B. napus* in Overton's story of component crops, it is noteworthy that he found the crop in probate inventories as early as 1588.[36] In the 1628-40 timespan, rape is similarly mentioned in a few inventories that document root crops. However as rape was

[34] Ibid., p. 208.
[35] Ibid., p. 201, 14.
[36] Ibid., p. 209.

sometimes the first crop planted in the late winter and early spring, and more often planted in the middle of June or July or even later in the season for a winter harvest, it is possible that Overton missed other mentions of *B. napus* by narrowly focusing his temporal boundaries of study to turnip and clover season. Yet it remains undisputed that *B. napus* was at least present in the same collections of inventories that uncovered an early abundance and increased density of Norfolk Rotation components.

This chapter builds upon Overton's study by illustrating the role of an alternative crop in the Norfolk Rotation. By mining the improvement literature for *B. napus*, my study returned a wide range of course designs that included rape and coleseed. Archival evidence shows *B. napus* in planting logs that depict the Norfolk Rotations and similar modified course designs. *B. napus* was clearly incorporated into series and rotations that primarily integrated the classic plants of the Norfolk Rotation—clover, turnips, wheat, and barley, oats, or sometimes rye. The first section focuses on The Norfolk Rotation for herd management and shows that rape played an important role as a fodder crop. The second sections explore alternative repetition schematics and the larger question of crop diversification.

II. Rapeseed in the Norfolk Rotation: Crop Diversification for a Resilient Design

We have already covered the importance of the rotation in the phase out the Medieval three field system, which also regenerated soils by rotation but limited productivity by cycling bare or other fallow through arable. As the village supported fewer animals, manure inputs were most beneficial when common herds were rotated through arable. However not all villages adopted this design, and private land owners were less likely to benefit. In contrast, land tilled as part of a course rotation could be used to grow both crops and feed for livestock over an almost endless number of years, thus establishing the principle of rotation farming. Instead of limiting animal foraging to common pastures, livestock grazed on turnips and clover planted as a green fallow cycle or survived on winter rations of turnips and rape grown in rotation with wheat or barley. However it was the introduction of rotations of nitrogen fixing legumes for fodder that had the greatest impact. In short, the Norfolk was powerful because it increased animal herd size by supporting food production for both humans and animals on the same land all while increasing the bioavailability of nitrogen. Yet as period actors did not think in terms of nitrogen fixation until later in the nineteenth century, it is important to reconsider the evolution of design elements that supported this breakthrough.

My claim is that period actors thought in terms of plant groupings more than taxonomic classification when designing rotations. If we set aside modern concepts of taxonomy to observe period uses of the plants used in course designs, we see that *B. napus* played several unique roles in the emergence of rotation farming. This suggests that period actors chronologically arranged plant groups by function more than they reproduced an ordering of particular species. Multiple grasses were interchanged, but rotations almost always included a grass planting and farmers often used this grass for grazing. Similarly, different animal feeds were planted, but there was often a planting of storable feed. Cash crops were often (but not always) cereals and rarely repeated. However oilseeds like *B. napus* also sometimes functioned as an apex cash crop in that the prior rotation prepared the soil for a robust yield. In other examples, *B. napus* is grown for grazing to prepare the soil for wheat or barley. *B. napus* makes for an interesting study because comparisons between courses show that it served multiple functions and appeared in the rotation as grass, fodder, cash crop, and improvement crop.

First, the integration of animals into the Norfolk for convertible husbandry highlight the role of *B. napus* as both a grass and turnip substitute, depending on the farmer's choice. While we have previously covered the combining of turnips and rape, it is important that this relationship also manifests in the specific designs used to build a course rotation. By the early nineteenth century, the descriptions of the Norfolk Rotation often confirm the integration of animals into the turnip cycle. In the 1815 *General View of the Agriculture of Lancashire,* Richard Watson Dickson writes that rape can be used in place of turnips in course design to protect against crop failure. He describes how "Mr. Roscoe grows turnips to a considerable extent… in somewhat the following courses: 1. Turnips, 2. Oats, 3. Clover, 4. Wheat; Or, 1. Swedish turnips, 2. Oats or barley, 3. Clover, mown once and fed, 4. Wheat, 5. Winter tares." Yet Dickson emphasizes that "where the turnips fail, rape is substituted, as a sheep feed, to be eaten off upon the land in autumn and in winter."[37] To the extent that planted grazing cycles facilitated the transition of permanent pasture to arable through convertible husbandry, farmers who adopted the Norfolk could support larger herds without expanding pasture or permanent grassland proportionately with increases in herd size. This outlines the same schematic described by our narrator from *Make Fruitful the Land*. He describes the Norfolk as unique because "plenty of winter food was grown for the animals, and crops and livestock were brought together in a close and effective farming system."[38] The Norfolk allowed farmers to support more animals on existing acreage because herds could graze on the turnips. However as the story of *B. napus* shows, crop diversification was a safety mechanism because plants that performed the same environmental function could be used interchangeably in the course.

[37] Richard Watson Dickson, *General View of the Agriculture of Lancashire, with Observations on the Means of Its Improvement* (Sherwood, Neely & Jones, 1815), p. 256.
[38] Annakin, "Make Fruitful the Land " 6 min.

We see another example of animals feeding off the fodder cycles of a modified course rotation in John Middleton's *General View of the Agriculture of Middlesex*, published in 1813. Middleton recommends feeding cattle off both the green and root crop cycle. He writes:

> The nature of corn crops requires, that it should not, on any account, be sown after either wheat, rye, or oats: the much better practice being, to sow it after turnips, potatoes, carrots, tares, &c.; and, in some cases, after hemp, flax, and rape. The land should not receive any further manure than the dung and urine deposited by cattle, during the time they were eating the preceding green or root crop off.[39]

Middleton describes the practice of fallowing and manuring for a wheat crop as an old doctrine long outdated. Instead he writes that "every man of superior skill in agriculture" sows wheat only after crops of rape, turnips, clover, or peas.[40] Such a design kept the land in more constant cultivation when compared to the longer fallow cycles that traded current productivity for future gains in wheat yields. The benefits of manure were gained by animal grazing of the rape or turnips prior to a wheat planting. Similarly, in the 1812 *General View of the Agriculture of the East-Riding of Yorkshire*, Henry Eustasius Strickland documents the integration of animals into rape fallows. Even when grown for seed, rape "is a very improving crop to the land, and when good, is superior in feeding to a crop of turnips," writes Strickland. Rape is then succeeded by a crop of wheat and sometimes oats, thus outlining a course similar to the Norfolk but without the grass planting. Strickland even cautiously integrates animals into seed producing fields. He writes "It is not an infrequent practice to feed off early sown rape with sheep in the autumn and afterward allow it to stand for a crop of seed, but care must be taken not to eat it too close as the produce would be there by diminished."[41] This last quote suggests that rape was allowed to

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[39] John Middleton, *General View of the Agriculture of Middlesex: With Observations on the Means of Its Improvement, and Several Essays on Agriculture in General. Drawn up for the Consideration of the Board of Agriculture and Internal Improvement* (London: Printed for Sherwood, Neely, and Jones; sold by G. and W. Nicol, 1813), p. 233.
[40] Ibid., p. 204.
[41] Henry Eustasius Strickland, *A General View of the Agriculture of the East-Riding of Yorkshire*, ed. Agriculture Board of (York: Printed for the Author, (T. Wilson and Son), 1812), p. 139-43.

regenerate from grazing over the course of a lengthened growing cycle in which it served both as a fodder and cash crop.

A more conventional Norfolk Rotation demonstrates the integration of rapeseed into both the grass and turnip phases in Dorset. In the 1812 *General View of the Agriculture of the County of Dorset*, William Stevenson describes the rough and coarse pastures of little value in the upland part of the county. "A great part of this land might be converted to tillage to the profit of both landlord and tenant," writes Stevenson. He recommends a six part course rotation to increase the stock. Stevenson recommends cropping 10 or 12 acres of down in the following manner: "1st year Turnips, 2nd Spring vetches fed off into turnips and rape the same summer, 3rd Oats or barley with grass seeds, 4th Grasses mown and the hay spent on the same field in the winter, 5th Grass or rape summer fed, 6th, Wheat or oats according to the nature of the soil."[42] Here the Norfolk is modified and extended to meet the demands of the soils in Dorset, which consist of chalk, gravel, and sand but are more fertile in the valleys.[43] This modification is accomplished with crop diversification. The use of rapeseed suggests that the grass planting is more important than the use of clover or any particular grass. The turnips are similarly interchangeable with vetches or rape, which suggests that grazing and manuring are the primary environmental goals of the rotation. However it is important that most designs segregate and stagger grass and turnip plantings, though the logic of this pattern is not usually explained by period farmers.

In 1813 in the Palatine of Chester, where soils are more fertile and consist of marl mixed with clay and sand, Thomas Wedge similarly illustrates the use of a Norfolk course rotation that uses rape in place of grass.[44] Unlike Dickson, who viewed rape as interchangeable with the root

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[42] William Stevenson, *General View of the Agriculture of the County of Dorset: With Observations on the Means of Its Improvement* (G. and W. Nicol, 1812), p. 336.
[43] GENUKI, "Dorset," https://www.genuki.org.uk/big/eng/DOR.
[44] "Cheshire " https://www.genuki.org.uk/big/eng/CHS.

crop planting, Wedge recommended using rape as a green crop in place of or along with clover. In his five course rotation, Wedge recommends a "green crop either of clover or rape and rye mixed to be eaten off with sheep…", however this cycle was sometimes replaced by beans or peas. He began with turnips, planted oats, then either peas or a green crop like clover or rape. The fourth cycle was wheat followed by turnips.[45] Alternatively, Wedge recommended planting tares in place of the rape or clover to mow for fodder or to make hay. In anticipation of the course, Wedge used lime to improve the turnips and sometimes paired and burned.

The versatility of *B. napus* as a design element tells a much larger story about the environmental strategy of Norfolk course designs, which may have formed through chronological plant type pairings rather than through a formula of species thought to have different environmental functions. Ultimately field design diversity in the form of the chronology of Norfolk supported a more flexible and robust landscape-level design in the form of longer-term rotations between permanent grass and arable field, though convertible husbandry also served to transition a greater percent of farmland in England from pasture to planted crop. As Riches writes of eighteenth century agriculture in Norfolk and the emergence of course farming, "Indeed, to some observers early in the century it seemed that the meat rather than grain production was characteristic of the new agriculture, but the real goal was a convertible husbandry, in which livestock helped to increase grain production by furnishing more manure and by consuming the crops necessary in the new scheme of rotation."[46] Riches does not highlight the importance of rapeseed to convertible designs, much less the importance of rapeseed in the course rotations used to convert permanent pasture to ongoing arable production.

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[45] Thomas Wedge, *General View of the Agriculture of the County of Palatine of Chester: With Observations on the Means of Its Improvement* (C. MacRae, 1794), p. 55-56.
[46] Riches, *The Agricultural Revolution in Norfolk*, p. 16.

But the double identity held by *B. napus* in the long eighteenth century is evident in its debut as both a root-like fodder and a grass substitute while also serving as a cash crop for oilseed. Rather than implementing a published or recommended course, the diversity of designs suggests that farmers respected the chronology of plantings even while substituting plants within functional categories. In this way the study of *B. napus* shifts the popular narratives of diffusion and density and abundance of adoption to questions of localized design innovation and integrated farming practices.

One particular example of rapeseed in course design illustrates that such categories were formed from pragmatism and empirical observation. In the "Essay on Rotation of Crops" which appeared in the 1833 *Farmers' Register*, Hamilton Couper offers eight principles of course arrangement that require site-specific selection of crops to meet the circumstances of "local position," and to devise a chronology so that "plants possessing a system of broad leaves are to be alternated with those having narrow leaves;" and fibrous rooted plants "are to be alternated with tap and tuberous rooted vegetables." Other recommendations advise against recurring plantings of the same crop, and insist upon the temporal staggering of reoccurring chronologies of those plants which require tillage. Manuring is recommended, but patterned so that soils are enriched prior to the most exhausting crop. This grand plan culminated in an eighth goal—"Land should be left bare as short a time as possible, and should be kept covered with plants valuable in themselves, or which contribute to the increased value of those which are to follow."[47] These recommendations are most impressive for supporting a rotation chronology defined by relationships between physiological and functional categories of plants rather than taxonomic, species-based categories. In contrast, much as our narrator begins his story of the

[47] J. Hamilton Couper, "Essay on Rotation of Crops," (1833), p. 12.

Norfolk Rotation, course design is often depicted in terms of a simple chronology of species: *Triticum aestivum* (wheat) is planted after a Fabaceae of some sort—usually clover, which follows *Hordeum vulgare* (barley) planted after *Brassica rapa subsp. rapa* (turnips). Though the archives rarely disclose the species of clover and turnips planted by period farmers, the modern species selection is imposed on this imagined, quintessential historical rotation.

Though Couper does not explain the role of leaf or root form in improving soils, his classification more closely resemble plant functional type ontologies often attributed to Alexander Von Humboldt, who first developed a classification system based on growth forms.[48] Modern plant functional type categories are based on resource use, response to environmental controls, and morphology or physiology and thus often put grasses and legumes under the same broad heading. Though unlike taxonomically related species which may have very different responses to the same environmental conditions, plants in the same functional category may not have similar reproductive structures but likely share ecological requirements or performance responses.[49] To use a modern example, the number of carbon atoms in the compound produced by photosynthesis is used to distinguish C3 cool season crops like wheat from warm season C4 crops, like corn.[50] Biome categories like artic and boreal are used for sub-categorizing so that broadleaf evergreen tropical trees are distinguished from broadleaf evergreen temperate trees.[51] While Couper's categories are perhaps more empirically based than scientifically tested through hypothesis and statistical analysis, he puts rape, flax, poppy, cameline and hemp in the

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[48] Paul Ramsay, Martin Kent, and Jennifer Duckworth, "Plant Functional Types: An Alternative to Taxonomic Plant Community Description in Biogeography?," *Progress in Physical Geography* 24 (2000): p. 518, Table 1.
[49] Ibid., p. Ramsay 516; Patricia Fara, *Sex, Botany and Empire : The Story of Carl Linnaeus and Joseph Banks* (Cambridge: Icon, 2003).
[50] Climate and Global Dynamics Laboratory, "Plant Functional Types," http://www.cgd.ucar.edu/tss/clm/pfts/index.html.
[51] Jean-François Lamarque et al., "Cam-Chem: Description and Evaluation of Interactive Atmospheric Chemistry in the Community Earth System Model," *Geoscientific Model Development* 5 (2012): p. 371, Table 1.

Oleaginous division, presumably based on the oil in the plant or seeds.[52] Cereals were in a second category, and legumes encompassed clover, sainfoin, and Lucern—three plants now considered grasses—as well as the modern legumes, beans and peas.[53]

From his plant type categories Couper designs a 12 year rotation carried out over 48 acres. The course begins with plants of the First Division. He writes "Rape, with stable and liquid manure, four acres, followed as a second crop, by two acres of carrots, beets or turnips." Following plantings from the other divisions such as wheat, beans, potatoes, barley, and clover, Couper again recommends "Plants of the First Division" such as flax and oil cakes in the seventh year. Rape is named again in the 10th and 12th years when it is grown for seed and as a crop after plants of the Third Division such as winter barley.[54] Here rapeseed functions as both a fodder, manure, and oilseed producing crop through an intricate integration with grass, root crop, and manure. According to Couper, the practical agriculturist observes such a course as a form of "economic succession" in that the labor of preparing the soil and getting crops ready for market may follow an easy and regular cycle of planting. Couper writes "Such are the principles of the convertible husbandry derived from the laws of vegetation."[55] He even cites the traditional four course of turnips, barley, clover, and wheat as his inspiration, though emphasizes that such a great paucity of plant variety also limited cultivation. "These limited rotations are, however managed with much judgement… The first is the celebrated Norfolk rotation—adapted to a sandy loom. The change which it has produced in the agriculture character of the country, is so notorious to be familiar to all."[56]

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[52] Couper, "Essay on Rotation of Crops," p. 13.
[53] "The third, Leguminous plants, as beans, peas, vetches, lentils, clover, sainfoin and Lucern." Ibid.
[54] Ibid., p. 12-14.
[55] Ibid., p. 12-13.
[56] Couper notes that the clover cycle in the Norfolk Rotation was often drawn out for two years, resulting in a five course design. Ibid.

Yet in her work on the Norfolk rotation, Riches suggests that more complex, longer schematics such as Couper's 12 course may have met resistance from some farmers for the extra work they involved. Even six courses were often a sign of influence from a landlord as the inclusion of alternative crops delayed the planting of cash crops like wheat. "The matter was considered of sufficient importance to be incorporated into the lease, the landlord usually insisting on a six-shift rotation such as wheat, barley or oats, turnips, barley or oats with clover, clover and the sixth year the land grazed until midsummer and then plowed for wheat again," writes Riches. Such a rotation is markedly different than the simple four course described by our narrator in *Make Fruitful the Land* as the demands of tillage, manuring, and animal relocation on the property required ongoing structural innovation. Yet Riches clarifies that this more elaborate course was not necessarily preferred by the tenant. "If not in the lease, the tenant was likely to contract this rotation to four courses—wheat turnips, barley, and clover," she writes.[57]

Based on my data mining of the more than 130 General Views published by the Board of Agriculture, six course cycles were indeed common, and here I provide four examples. From the use of terms like "course," "rotation," and "series" as well as by utilizing plant names in keyword search and data mining queries, I can also provide examples of seven and eight course designs. Returning to Dorset, Stevenson describes an eight course on the strong, chalky and flinty loams in the bottoms where pasture and meadow attach to arable. He writes "…the course is as follows 1 Turnips, rape manured after ploughing in the winter and spring, 2 Potato, oats, 3 Bearis vetches which are drilled and horse and hand hoed, 4 Wheat, 5 Turnips, rape, 6 Potato oats sown with clover, 7 Clover, 8 Wheat."[58] In Durham, Joseph Granger similarly describes a

[57] Riches, *The Agricultural Revolution in Norfolk*, p. 82-85.
[58] Stevenson, *General View of the Agriculture of the County of Dorset: With Observations on the Means of Its Improvement*, p. 191.

course that consists of seven plantings. Two tables (see below) represent multi-year planting logs for nine to ten different fields. The first table intermixes rape and turnips between plantings of oats, wheat, and clover.[59] The second table shows a proper Norfolk course with the exception that rape is substituted for the turnips in a pattern that repeats grass plantings and includes a fallow cycle. This prepares the soil for two cycles of wheat. Finally, in the Palatine of Chester, Thomas Wedge similarly documents a perfect six course Norfolk with rape included in place of turnips (see below). The repetition of grass and integration of a fallow extends the course into six cycles.[60] These examples are striking for integrating rape into the traditional list of Norfolk crops, resulting in a longer course.

In other examples rape is integrated into courses that have very little resemblance to the Norfolk, thus highlighting period awareness of plant type pairings. For example, Arthur Young documents several courses that include rape.   In the 1799 *General View of the Agriculture of the County of Lincoln* he notes an eight course at Garthorpe in the Marsh where new land was broken up with the following "1 Flax, 2 Rape, 3 Potatoes, 4 Flax, 5 Rape, 6 Potatoes, 7 Flax, 8 Wheat." Designed for lightest sand, this course had the potential to maintain successive plantings without a fallow for a decade or more.[61] In 1810 John Bailey described a seven course rotation in the *General View of the Agriculture of Durham*. Here rape was repeated twice followed by two

[59] Joseph Granger, *General View of the Agriculture of the County of Durham, Particularly That Part of It Extending from the Tyne to the Tees: With Observations on the Means of Its Improvement* (C. MacRae, 1794), p. 40.
[60] Thomas Wedge, *General View of the Agriculture of the County Palatine of Chester with Observations on the Means of Its Improvement*, ed. Agriculture Board of, Goldsmiths'-Kress Library of Economic Literature ; (London: Printed by C. Macrae, 1794), p. 238.
[61] Arthur Young, *General View of the Agriculture of the County of Lincoln*, ed. Board of Agriculture (W. Bulmer and Company, 1799), p. 104.

plantings of oats. Next came barley and a third round of oats before a final planting of barley. However this was sometimes shortened to a course of rape, barley, beans, wheat, and oats.[62]

Of course shorter series are also well documented and at times recommended above a course rotation. From these progressive chronologies of plants that culminate in a cash crop but do not demonstrate a full course, much less a rotation, we see the foundational plant relationships upon which the Norfolk was founded. In Nottingham some planted barley, oats, and rape followed by another round of barley.[63] In Essex in 1794 we similarly see rape or coleseed alternated with wheat on rich, loamy soils.[64] In this same year in the County of Hants, Abraham and William Driver describe a series planted in tidal flood plain that consists of wheat, barley, oats, cabbage, and finally rape.[65] In Chillingham and Northumberland George Culley and John Bailey describe tillage cycles of only three years, "…the first year oats; second, fallow—turnips or rape; the third, wheat or oats or barley sown up with clover and ray grass, and depastured with sheep for three, four, or five years." Returning to the Cultivation Tables at Boynton and Carnaby, a simple three course rotation titled "Rich and Sawden's Cultivation" shows rape planted as a stand-alone crop with oats and grass from 1834 to 1836.[66] We also see turnips combined with rape in two course plantings six course planting on George Riby's land in 1835 to 1840. This demonstrates the rotation of livestock onto longer planted cycles in between arable rotations. In contrast, the Norfolk helped reduce the amount of time that a plot of land was kept

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[62] John Bailey et al., *General View of the Agriculture of the County of Durham, with Observations on the Means of Its Improvement. Drawn up for the Consideration of the Board of Agriculture and Internal Improvement. By John Bailey* (Richard Phillips, Bridge-street, 1810), p. 223.
[63] Robert Lowe and Board of Agriculture, *General View of the Agriculture of the County of Nottingham: With Observations on the Means of Its Improvement* (C. MacRae, 1794), p. 108.
[64] Griggs Messrs, *General View of the Agriculture of the County of Essex with Observations on the Means of Its Improvement*, ed. Board of Agriculture (London: Printed by C. Clarke, 1794), p. 12.
[65] Abraham Driver, *General View of the Agriculture of the County of Hants with Observations on the Means of Its Improvement*, ed. William Captain Driver, et al., Goldsmiths'-Kress Library of Economic Literature ; (London: Printed by C. Macrae, 1794), p. 59.
[66] "Cultivation Tables at Boynton and Carnaby, Charlston."

VENTY-ONE YEARS.

1808	1809	1810	1811	1812	1813	1814	1815
Grass	Grass	Oats	Rape	Wheat	Clover	Fallow	Wheat
Grass	Oats	Rape	Wheat	Clover	Fallow	Wheat	
Oats	Rape	Wheat	Clover	Fallow	Wheat	Grass	
Rape	Wheat	Clover	Fallow	Wheat	Grass	Grass	
Grass	Grass	Grass	Grass	Grass	Grass	Grass	
Grass	Grass	Grass	Grass	Grass	Grass	Grass	
Hop and White Clover and Rye Grass	Grass	Grass	Grass	Grass	Grass	Grass	
Wheat	Hop and White Clover and Rye Grass	Grass	Grass	Grass	Grass	Grass	
Grass	Grass	Grass	Grass	Grass	Grass	Grass	

ould be in grass, and the other two third parts, turnips and barley in cultivator of a water-shaken farm, to rear young cattle and horses, and keeping them on new laid lands in wet seasons. It is not, however, l occasionally with some part of the other, which is meliorated, and

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1809	1810	1811	1812	1813	1814	1815
Hop and Vhite Clover and Rye Grass	Grass	Grass	Grass	Grass	Grass	
Grass	Grass	Grass	Oats	Rape	Wheat	
Grass	Oats	Rape	Wheat	Turnips	Barley	
Grass	Grass	Oats	Rape	Wheat	Grass	
Barley	Grass	Grass	Grass	Oats	Turnips	Barley
Turnips	Barley	Hop and White Clover and Rye Grass	Grass	Grass	Oats	
Wheat	Turnips	Barley	Hop and White Clover and Rye Grass	Grass	Grass	
Rape	Wheat	Turnips	Barley	Hop and White Clover and Rye Grass	Grass	
Oats	Rape	Wheat	Turnips	Barley	Clover	
Grass	Grass	Grass	Grass	Grass	Grass	

ie before it is repeated; and as it comes into grass, all the manure bred upon the pre-
short a time under the plough. Such is the method that might probably be pursued with
future preservation of it. For land we call *water-shaken*, a different rotation and treat-
ur parts, and the whole managed according to the annexed scheme of husbandry.

4.5 *Planting Calendars from Dhurham, 1809-1815 (left) and 1808-1815 (right).* The tables show rape (highlighted in yellow) in a six and seven course rotation. The pages were either printed or digitized with a left margin cut, but text confirms the rotation.[67]

[67] Note that the dates in the tables (1809-1815) post-date the book's publication year (1794). I cannot reconcile this detail because I do not have access to rare books libraries during the pandemic in order to compare editions and look for reprint dates or signs of re-binding. Granger, *General View of the Agriculture of the County of Durham, Particularly That Part of It Extending from the Tyne to the Tees: With Observations on the Means of Its Improvement*, p. 39-41.

in pasture so that the entire cycle consisted of only a year or even a season of planted fodder grazed by sheep or cattle.[68]

As these sorts of smaller rotations gave rise to the more sophisticated designs that supported on-going productivity, England became better able to support a growing industrial sector without a proportionate increase in arable acres planted. According to Riches, "these changes were fundamental; and no mere invention of "drill rollers" or mowing machines, or other ways of getting seed into the ground and crops into the barns, could have increased production as crop rotation did, for it increased the productivity of the soil itself."[69] Mechanical technologies and crop introductions may have streamlined planting practices, but late eighteenth century designs solved the pragmatic problems of site-specific implementation under variable environmental conditions through chronological diversification and the use of alternative species.

III. Paring and Burning and the Norfolk Rotation

Paring and Burning has received less attention in the literature of the British Agricultural Revolution than The Norfolk Rotation, but in a few of the examples that use rapeseed as part of an extended course rotation, we also see burning integrated into the cycle. This is perhaps one of the most basic but elegant examples of technology combining in the period as the chronological spacing of newly introduced fodders with improved burning methods was thought more effective than either strategy used alone. As paring and burning was also used to kill pests, there may be a unique environmental impact from combining slow beat burns with a modified Norfolk or other

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[68] John Bailey and George Culley, *General View of the Agriculture of the County of Cumberland: With Observations of the Means of Improvement*, ed. Board of Agriculture (London: C. MacRae, 1794), p. 33.
[69] Riches, *The Agricultural Revolution in Norfolk*, p. 16.

course design that included plantings of *B. napus* or the tillage of its cake and meal.[70] As both rape planting and manuring offer gentle soil pathogen suppression effects, this section considers designs that may have influenced the progression of course design by combining fire and plant technology.

Eric Kerridge traces the removal of sward ground covered with grass or moss for burning in his classic work *The Agricultural Revolution*.[71] The top layer of soil was usually removed by hand, spade, or one of two ploughing technologies that either stripped the cover from the entire field or rather cleared rows of land for planting. The fragmented herbage or 'beat' was then gathered in heaps of five or six bushels each called 'beat-burrows' or simply 'burrows' to be burned so that ash could be spread. It was the windward side of each burrow that was ignited with a wisp of rough straw, likely because this fed the smoldering heat in the moist heap during the several months that it took to reduce the pile to ashes. After the beat was burned to a fine ash and spread over the surface, the first crop was often wheat, though rye was grown on poorer lands. The first crop was followed by barley and then oats, though only on the best of lands. Deeper soils were well manured and bare-fallowed in the penultimate year of tillage.

Though Kerridge neglects the role of rapeseed, it is also possible to find the yellow flowering seed plant documented as the first crop after paring and burning. John Tuke described this practice in his 1794 *General View of the Agriculture of the North Riding of Yorkshire*. According to an anonymous local from Lockton moor who Tuke quotes, "Forty-eight acres were pared and burnt, and sown with rape (except about an acre sown with rye), the produce about

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[70] Eric Kerridge, *The Agricultural Revolution* (New York: A.M. Kelley, 1968), p. 151-53.
[71] Ibid.

'ENTY-ONE YEARS.

1808	1809	1810	1811	1812	1813
Grass	Grass	Oats	Rape	Wheat	Clover
Grass	Oats	Rape	Wheat	Clover	Fallow
Oats	Rape	Wheat	Clover	Fallow	Wheat
Rape	Wheat	Clover	Fallow	Wheat	Grass
Grass	Grass	Grass	Grass	Grass	Grass
Grass	Grass	Grass	Grass	Grass	Grass
Hop and White Clover and Rye Grass	Grass	Grass	Grass	Grass	Grass
Wheat	Hop and White Clover and Rye Grass	Grass	Grass	Grass	Grass
Grass	Grass	Grass	Grass	Grass	Grass

ould be in grass, and the other two third parts, turnips
cultivator of a water-shaken farm, to rear young cattle a
f keeping them on new laid lands in wet seasons. It is
d occasionally with some part of the other, which is m

4.6 *Planting Calendars from the Palatine of Chester, 1794.* The tables show rape in a six course rotation. The pages were either printed or digitized with a left margin cut, but text confirms the rotation.[72]

[72] Wedge, *General View of the Agriculture of the County of Palatine of Chester: With Observations on the Means of Its Improvement*, p. 39-41.

sixty quarters; the rye grew very strong, and in height not less than six feet, and was sold while standing for five guineas."[73] Afterwards, part of the land was sown down with oats and clover to complete an enclosure process. The value of the land increased from only one shilling per acre, or 48 shillings total, to £30 per annum. In a second example in the same work, rape plantings were recommended after paring and burning on all soils, except where too wet, to facilitate conversion of grasses to arable. In this case the rape prevented the roots of grass from taking hold.[74]

Such examples of *B. napus* integration are important because "Beat-burning was a defense against wire-worm and other soil pests and enabled wheat to be grown as a first crop," writes Kerridge.[75] This is because wireworms and their eggs were killed when the soil was burned, though the paring of moss and grass to burn also cycled carbon and nutrients into the soil to support a more competitive ecology that displaced various pathogens. As Kerridge describes every detail of the technology, we see how burns were integrated into a system of manuring and series plantings designed to maximize the number of cash crop plantings. Kerridge describes a traditional three courses of oats followed by a nursed ley after paring and burning in Lancashire and Cheshire. After beat burning, the land was sometimes capable of repeated cycles of wheat.[76] "More commonly, two successive crops of wheat preceded one or two of oats. Barley could not be grown after wheat in any but the best lands. Deeper soils, well-manured and bare-fallowed in the penultimate year of tillage, could often be forced to bear four or five crops…" writes Kerridge when describing the first years after beat burning.[77] Yet period improvement manuals

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[73] John Tuke, *General View of the Agriculture of the North Riding of Yorkshire with Observations on the Means of Its Improvement*, ed. Agriculture Board of, Goldsmiths'-Kress Library of Economic Literature (London: Printed by W. Bulmer, 1794), p. 109.
[74] Ibid., p. 55.
[75] Kerridge, *The Agricultural Revolution*, p. 152.
[76] Ibid., p. 226, 151-3.
[77] Ibid., p. 152.

suggest that course rotations were also adopted after burns to extend this fertility, and rapeseed plantings were often recommended as the first crop in the course. Some farmers even include paring and burning in place of a first planting in a six course design.

We see a similar approach in Young's discussion of the Lincoln case. Young describes the courses used by a Mr. Elmhurst to grow wheat. In one example, Elmhurst lists burning as his first phase in a longer design that includes two plantings of rapeseed. "But this very intelligent cultivator on cold or strong clay land, old pasture, proceeds in the following course: 1. Pare and burn for rape. 2. Rape. 3. Rape. 4. Battledore barley. 5. Wheat. 6. Seed left for sheep & c."[78] Here we see paring and burning integrated directly into a course design that uses double plantings of rapeseed in order to facilitate successive cereal plantings. Though this schematic includes sequential plantings of barley and wheat and thus violates one central goal of the Norfolk Rotation—the staggering of cereal crops between root and grass plantings. However this innovative design accomplishes a far more lucrative five course with the help of alternative forms of regeneration. William Stevenson in Dorset similarly used paring and burning to convert land to a more traditional seven course of turnips, vetches, turnips and rape, oats, grasses, rape, and wheat. This design integrated grazing into the first cycle in order to transition 10 to 12 acres of down to arable. "The first process for converting such lands into tillage, ought undoubtedly to be that of paring and burning," writes Stevenson.[79] In another example from West Norfolk, Stevenson described how rape was integrated into a course design in order to break up inferior soil used for sheep pasture or rabbit warrens for rotations of cereals. These

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[78] Young, *General View of the Agriculture of the County of Lincoln*, p. 110.
[79] Stevenson, *General View of the Agriculture of the County of Dorset: With Observations on the Means of Its Improvement*, p. 336.

examples highlight period trials of course designs that maximized on-going plantings of wheat and cereals with the use of regenerative methods.

In an excerpt from *The Code of Agriculture* published in the *Genesee Farmer & Gardeners Journal* in 1835, Francis Blaikie describes four rotations that farmers could implement according to their local soil type. To cycle pasture and cereals through light soils, Blaikie advises:

> That land, when broken up, is usually pared and burned, and sown with rape for the first crop; 2. Rye or oats; 3. Turnips well manured, and all the crop eaten upon the ground by mixed stock….. 4. Barley, well seeded with white clover, narrow-leaved rib grass, and other permanent grasses; 5. Pastured, and so continued for a series of years until the moss plants overcome the grasses; when the ground is again broken up, and undergoes a course of aration as before."[80]

If clover were planted for pasture, this example would approach the specifications of a proper Norfolk with the exception that barley is substituted for wheat. However this example is unique for detailing the rotation as part of the course design. It is often assumed that courses were repeated by period farmers, however very few texts explicitly detail the repetition of the planting chronology. Some convertible practices left the land in pasture for many years at the end of the course. Yet here it is clear that land underwent continued cropping, manuring, and applications of lime through the implementation of a detailed course design. Interestingly, Blaikie's other courses recommend turnips, barley, clover, and wheat but advise manuring to accomplish this rotation. It is clear from his lengthy complaints of the expense of rape cake that this option was frequently used as a manure. He mentions no other manuring options, and warns that "…the average price of rape cake, including the expense of breaking the same into a powdered state, has, in the last ten years, been about £5 10s. a ton, and that quantity is usually allowed to three

[80] Francis Blaikie, "From the Code of Agriculture, of the 5th Edit. On the Rotation of Crops on the Estate of Holkham.," (1835), p. 294.

acres of land…". This highlights the multiplicity of technology integrations that harnessed *B. napus* for course design as a crop and manure.

In 1785 David Young published *National Improvements Upon Agriculture: In Twenty-Seven Essays* to detail the practices for convertible and new agriculture. To drain moss, Young recommends paring and burning. "After the ashes are spread, it will be in great order fit to produce a very luxuriant crop of any kind of grain such as wheat, barley, oats, or rape seed…," writes Young.[81] Here rape is considered a grain and functions as a cash crop, thus echoing the practice of repeated cash crop plantings following a burn described by Kerridge. "Good moss when pared and burnt often produce an amazing crop of rape seed…" continues Young.[82] Later in the article he recommends that when rape seed is planted in July or August, it will be ready to be cut down in the July of the following year. After the rape seed is "taken off," Young recommends sowing ten pounds of white clover, six pounds of yellow clover, six pounds of rib grass, and three or four bushels of natural hay seeds.[83] This strategy was used to support permanent pasture for grazing. "Whenever the pasture begins to fail, then renew the process of paring and burning as before directed," writes Young, who warns that cattle should initially be kept from the pasture to protect the second year crop of rape seed.[84]

Though these examples are anecdotal, they uncover an intricate relationship between paring and burning, rape, and the mature series or emerging course design. As early as 1766 authors like Charles Varlo were categorizing the two subjects into the same chapter. In *A Treatise on Agriculture, Intitled the Yorkshire Farmer,* Varlo includes a chapter titled

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[81] David Young, of Perth, *National Improvements Upon Agriculture : In Twenty-Seven Essays* (Edinburgh: Printed by J. Bell, 1785), p. 12.
[82] Ibid., p. 13.
[83] Ibid., p. 14.
[84] Ibid.

"Directions How to Raise Rape and Cole-Seed, and Also How to Manage Burn-beating." After cutting sods two feet long, the strips of earth and grass were dried and burned in heaps with the grass side downward.[85] The ashes were spread, and rape was planted.[86] The soil was then manured for spring barley and a subsequent wheat crop, though sometimes turnips were planted the same year that the rape was harvested.[87] According to Varlo, the oil from the seed was not the only product as the ashes from the burnt rape straw were sold to soap makers, and after the sheep grazed on the crop, the stubble could be transplanted for a crop of seed.[88]

Yet despite the preponderance of literature that links burning and rape through course design, the practice was not without controversy. To the extent that paring and burning were disliked, rape seed was also questioned. Depending on the soil type, this combination was thought promethean for the short term gains in productivity that could not be sustained over the long term. In 1794 Thomas Wedge complained that "Paring and burning is often very injudiciously applied: where the soil is thin, it is always improper; and where the turf is fine, and the soil good, it is needless."[89] He continued the opposing interests of tenant farmers and landlords by writing:

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[85] Charles Varlo *A Treatise on Agriculture, Intitled the Yorkshire Farmer. In Two Volumes. This Treatise Explains and Exemplifies ... Methods of Husbandry, and of Reclaiming Bog and Mountain ... Also a Monthly Kalendar of Works ... With Several Cuts of Machines, Tools, &C. Likewise ... Offered to the Legislature, and Friends of Ireland, a Scheme for Maintaining the Poor Thereof. ... By Charles Varley*, 2 vols., vol. 1 (Dublin: printed for the author, by Alex. M'Culloh, 1766), p. 218-19.
[86] Ibid., p. 220.
[87] Ibid., p. 222, 28.
[88] Ibid., p. 226, 28.
[89] Wedge, *General View of the Agriculture of the County of Palatine of Chester: With Observations on the Means of Its Improvement*, p. 55.

> Where tenants are at liberty to manage in their own way, the land is often very improperly cropped after this mode of management: it is frequently sown with rape, which stands to seed; next with wheat; then oats; perhaps for two or three years. It is no wonder, where such management prevails, that paring and burning should be in disrepute with landlords. The ashes certainly make the soil very fruitful for a time; but if it be not kept supported with manures but constantly cropped, it becomes in a few years so exhausted, as to be little better than a *caput mortuum*.[90]

According to Wedge, the better farmers planted rotations of oats and turnips for fodder in place of rapeseed. When rape was excluded from the rotation and the land was properly managed after pairing and burning, this practice was "generally esteemed both by landlord and tenant the best and most profitable mode of breaking up old, coarse pasture ground."[91] Sometimes paring and burning was successfully followed by barley, though in other excerpts from the same work, paring and burning is said to support two or three crops after which the land "suffered ever after."[92] This highlights the importance of the Norfolk Rotation, which differed from the three courses of cereal that traditionally followed paring and burning in that wheat plantings were divided by clover and turnips. In the Norfolk Rotation, wheat was not planted in two consecutive growing seasons.

This opposition to rapeseed in pairing and burning confirms its prevalence, even if by expanding on its role as a nuisance in the larger course of conversion from pasture to arable. The shorter courses of crops in the examples that illustrate the harms of paring and burning also offer a basis for contrasting the longer rotations that include rapeseed in a course designed to regenerate soils between plantings. Though paring and burning has a much longer history in the English landscape, this study shifts the debate over improvement to the question of design innovation by tracing its coupling with *B. napus* and rotation practices. Even contrarian

[90] Ibid.
[91] Ibid.
[92] Ibid., p. 52.

conversations that offer criticism are a sign of localized diversification of crop, chronology, and technology combining. By tracing *B. napus* through the course rotation, we also see the importance of paring and burning to the evolution of series and course design. Though similar components are used in modern fields in the form of biochar application, clover for fixation, *B. napus* for oilseed, and of course turnips for fodder, we rarely see these diverse elements combined in any chronological order in the same field. If the design modifications developed during the eighteenth century benefitted soils, the inclusion of paring and burning with rape into courses may prove helpful to modern farmers.

IV. Introduction Chronologies

Technology must "catch on" in order to have an impact. Along with period evidence that farmers used a technology to improve yields or debated its best application, the pattern of widespread adoption combined with geographic disbursal over time illustrates its role in agricultural improvement. However if we shift focus to design innovation, it becomes increasingly difficult to trace the diversification of coupled technologies over the landscape, much less in multiple regions through time. As even Mark Overton struggled to locate each component of the Norfolk Rotation on the same site in his study of probate inventories, and as Naomi Riches was unable to trace Norfolk course plantings beyond anecdotal archival examples, we might expect that a more complex study should fail for requiring, *B. napus,* paring and burning, or some indication of plant functional group diversification in addition to a Norfolk Rotation on many acres over multiple sites. Alternatively, introduction chronologies may fail to answer questions of local adoption and disbursal, but they at least suggest the length of the relationship between technologies in a region, and when two technologies overlap in the landscape over time, there is a stronger possibility of technology combining. When combined with the sort of archival evidence offered in the prior sections, this second piece of the puzzle helps pin down the history of design. This section considers the overlapping histories of *B. napus*, turnip, and clover introduction to understand the respective roles played by these crops in the evolution of the Norfolk Rotation. To make this argument in full, I need to move back to the sixteenth and seventeenth centuries briefly to consider the introduction of clover and Brassica. By investigating these crops, we can see more clearly that rotation design rather than initial introduction marked the major leap forward in productivity.

One of the earliest examples from Norfolk County of a four course rotation dates to 1573 but make no mention of clover or turnips.[93] To the contrary, Mauro Ambrosoli found that clover is first mentioned in works from the British Isles in the late seventeenth century.[94] Though botanists knew of the existence of clover and sainfoin, these leguminous grasses did not frequently appear in accounts of agricultural practices or crop calendars until the eighteenth century.[95] From this, Overton cautiously argues that the Norfolk course rotation of wheat, turnips, barley, and clover only became common in the nineteenth century.[96] Regardless of the chronology of widespread adoption, it is clear that the English course rotation had at least a century-long relationship with clover before the Norfolk became commonly documented in period texts. As this points to a slow and less progressive evolution of the Norfolk, is it possible that a wider range of designs were tested and circulated?

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[93] Riches, *The Agricultural Revolution in Norfolk*.
[94] Mauro Ambrosoli, *The Wild and the Sown : Botany and Agriculture in Western Europe, 1350-1850*, ed. Thirsk Joan, Past and Present Publications (Cambridge England ; New York: Cambridge University Press, 1997), p. 281-82.
[95] Ibid., p. 374-7.
[96] Overton, "The Diffusion of Agricultural Innovations in Early Modern England: Turnips and Clover in Norfolk and Suffolk, 1580-1740," p. 119.

By interrogating the *B. napus* introduction history as it altered soils at the landscape scale, we see the trend towards tinkering in the form of revised and applied practices. Rather than inventing or introducing a new agricultural and milling design, England may have been most innovative for its ability to combine and re-sculpt existing practices imported from the continent. In fact, *B. napus* is an ideal case study for the chronology of design innovation because it was introduced from France and the Netherlands in the late sixteenth and early seventeenth centuries, long before England could claim any economic or technological advances over her continental competitors.[97] We may not be able to place clover and *B. napus* in rotation on the average farm in in the seventeenth century, but we can show overlapping industrial-scale introduction histories.

Joan Thirsk is one of the few historians to explore the 'first introduction' of *B. napus* to England. Her sophisticated and detailed use of the economic history of rapeseed oil market locates the crop in the landscape as early as the late sixteenth century.[98] The impacts on England's textile market were profound, but the fear of olive oil scarcity also stood to limit technology development. Exporting broad cloth to Amsterdam and other parts of Europe for finishing was not only precarious but hindered domestic innovation. This early stage of the oil industry, as well as the arrival of religious refugees from Holland and France who were skilled in seed oil technologies, preluded the grand debut of Benedict Webb's rape oil mill, which is often used to mark the birth of the rape oil industry in England."[99]

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[97] G. E. Fussell, "History of Cole (Brassica Sp.)," *Nature* 176, no. 4471 (1955); Joan Thirsk, *Alternative Agriculture: A History from the Black Death to the Present Day* (Oxford: New York : Oxford University Press, 1997); "Alternative Crops: The Successes," in *Alternative Agriculture: A History from the Black Death to the Present Day* (Oxford: New York : Oxford University Press, 1997); *English Peasant Farming; the Agrarian History of Lincolnshire from Tudor to Recent Times* (London: Routledge & K. Paul, 1957).
[98] Joan Thirsk, *Alternative Agriculture: A History From the Black Death to the Present Day*, 1997, *Alternative Agriculture: A History from the Black Death to the Present Day*. p. 73-4.
[99] Ibid

By the late seventeenth century, rapeseed was clearly documented in Gloucestershire, Yorkshire, Edinburgh and in many places.[100] It became abundant in parts of the West Midlands and was common on the Isle of Asholme and the Hatfield Levels as well as in the Welsh countryside and on farms outside London and Bristol. In the 1660s the Committee for Trade began to regulate exports of rape oil in order to ensure supplies for local clothiers, and by the end of the seventeenth century, rapeseed grew from the southernmost tip of England to Scotland, and it continued to expand into new geography during the eighteenth century.[101] Thirsk confirms both the rapid diffusion of rapeseed across the countryside and the scale of early rape enclosures in a detailed history that harnesses the economic development of the industry to trace geographic disbursal into the eighteenth century.[102]

In contrast, while the earliest examples of turnip field enclosures also date to the mid-seventeenth century, the scale of planting was consistently less. To forward his controversial thesis of an early and rapid British Agricultural Revolution, Eric Kerridge published a 1956 investigation showing turnip introduction in High Suffolk as early as the mid-seventeenth century. By estimating the rate at which turnips were planted in fallow, Kerridge shows that field turnips were grown at the scale of about 40 acres to feed dairy cows and livestock at least twenty-five years before Turnip Townshend was born. Kerridge cites Adolphus Speed's 1659 *Adam out of Eden*, which details the production of turnips in fallows outside of London to fatten cattle for market. Since the tillage was fallowed every third or fourth year for winter corn and about half this fallow was sown to turnips, Kerridge estimates the seventeenth century planted

[100] Thirsk, *Alternative Agriculture: A History from the Black Death to the Present Day*, p. 74-8.
[101] Ibid.
[102] Ibid. Kerridge, *The Agricultural Revolution*, p. 236-7.

fallow acreage to show that turnips accounted for about one-eighth of tillage and one-half the summer and autumn sowings.[103]

Yet if we instead embrace this competing chronology that places turnip introduction in the mid-eighteenth century, it seems unlikely that field turnips were widespread across many counties during the prior century. Like Thomas Babington Macaulay, Lord Ernle, and many other nineteenth and twentieth century historians of the British Agricultural Revolution, popular writers of the late nineteenth century credited turnip innovation to Lord Charles Townshend—the man many still believe transformed English garden turnips into a planted fallow crop for grazing and feed in the 1730s. In his 1890 article "Turnip Husbandry" W. Wealands Robson adds to this classic story that while the turnip was well established in England by the end of the reign of Charles II, it was only during diplomatic trips to Germany that Townshend first saw the crop scaled to the field in a planted fallow. Townshend regularly joined King George I in Herenhausen from where he ruled Britain for half the year from Germany under the Hanoverian succession, and here the animals were largely fed indoors. "If that man is a benefactor to his species who makes two blades of grass grow where one grew before, what must the Marquis of Townshend have been to have found food for nations and generations?" writes Robson.[104] Though as Lord Townshend never published a treatise on turnips and left few primary sources on his experiments, it is difficult to distinguish folklore and fact when debating his role as the founding father of turnip husbandry or his use of turnips for environmental design. Historians

[103] "Turnip Husbandry in High Suffolk," *The Economic History Review* 8, no. 3 (1956): p. 392. It is impressive that inventories detail these uses of turnips and allow Kerridge to determine an early introduction to High Suffolk sometime between 1646 and 1666. Kerridge similarly outlines the widespread use of convertible husbandry in late sixteenth and seventeenth century England, however most of his examples illustrate lay rotations or marsh conversion and say little about the importance of herd increases. Though Kerridge does show that turnips were used for winter feed and planted fodder much earlier than Turnip Townsend's work at Raynham, he does not go so far as to tackle the question of turnip introduction into a robust system of convertible husbandry.
[104] W Wealands Robson, "Turnip Husbandry," *The Monthly chronicle of North-country lore and legend* 4, no. 37 (1890).

like C. Peter Timmer and Mark Overton suggest that Townshend was raised on a farm that grew field turnips for fodder, perhaps as a planted fallow. Letters between Townshend's staff at his Raynham estate and his brother-in-law, the prime minister Robert Walpole, highlight a four-course rotation that used turnips for animal feed as early as 1701.[105] Field turnips were at least grown for feed at least twenty years before Townshend retired to conduct agricultural experiments, pointing to a middle ground between the Kerridge thesis and the more popular rendition of events.

As clover, sainfoin, and Lucerne are similarly thought to have been limited to botanical trials during the seventeenth century, these crops would have been less likely to find their way into fodder fields than rape or turnips. However according to Ambrosoli's reconstructions of seed prices, the market for clover and Lucerne soon began to get larger even while remaining erratic. As early as the 1690s, figures for clover and Lucerne were high.[106] Edinburgh seed merchants document sales of red clover-seed and white clover to gardeners in the 1720s, though in small quantities.[107] English seed was produced domestically and began to compete with clover seed from Holland, Flanders, and Northern France. By the middle of the eighteenth century, clover was more frequently found in the inventories of seed merchants throughout the country. In 1789 William Marshall wrote that the cultivation of clover fields only went back fifty years or so in the west of England, though at the time he was writing, it appeared on two thirds of the enclosed arable land and on much of the common land. The rotation of wheat, barley, oats, and clover became obligatory in rent contracts, thus popularizing the crop.[108] In

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[105] C. Peter Timmer, "The Turnip, the New Husbandry, and the English Agricultural Revolution," *Quarterly Journal of Economics* 83, no. 3 (1969): p. 101-2.
[106] Ambrosoli, *The Wild and the Sown : Botany and Agriculture in Western Europe, 1350-1850*, p. 370.
[107] Ibid.
[108] Ibid., p. 375.

Northumberland and Cumberland red and white clover were grown successfully on leys. Red clover was grown in rotation with wheat in the enclosed fields of Middlesex.[109] Ambrosoli continues to detail the many geographies where clover was planted until it becomes clear that the vast span of England and Scotland were covered by the end of the eighteenth century.[110]

Though the consistency of a crop in the landscape over time does not necessarily reflect a standardized, persistent form of production, the innovative combinations that we see in the Norfolk Rotation in the late-eighteenth century would have been an ambitious leap forward if rapeseed, turnips, and clover had only been introduced just a few years prior. The manure demands of rape and turnips combined with other details of integrated design point to a long history of trial and error before the chronological patterns became so robust as to support the permanent downsizing of pasture and leys in favor of continuous arable cropping. For example, Mark Overton argues that turnips were so badly grown at the large scale during much of the seventeenth and early eighteenth centuries that the crop was of little value for winter feed. This perhaps explains why turnips occupied less of the total acreage on a farm during this time. He described innovation in Norfolk by saying: "…even in the most famous and progressive agricultural county, the major impact of turnips was after 1750, facilitating a reduction in bare fallows, assisting in the reclamation of light land, and providing more fodder for sheep and cattle."[111] In Norfolk about half the farmers were growing turnips by 1720, yet turnips represented only about 7 percent of the cropped acreage in Norfolk from 1660-1739. The percent of acreage in turnips only jumps to 24 percent in the 1830s.[112] In a second algorithmic

[109] Ibid., p. 376.
[110] Ibid., p. 369-80.
[111] Mark Overton, "Re-Establishing the English Agricultural Revolution," *The Agricultural History Review* 44, no. 1 (1996): p. 9-10.
[112] Ibid.

analysis cited by Bob Allen and others, Overton shows that the fraction of farmers in East Anglia growing turnips increased from about 10 percent to 50 percent between 1680 and 1710.[113]

Most importantly, at the time, turnip crops were not particularly robust or well grown. We cannot even assume that turnip bulbs became larger as technology developed, as period actors express favoritism for smaller roots. For example, William Amos wrote “it is an experimented fact, that the smaller the turnip, the longer it will resist the winter’s frost.”[114] Bulb size may or may not have matured in the late seventeenth and early eighteenth century, and the disbursal and adoption history may not be a helpful reflection of evolution towards a more robust design. Thus, the typical indicators of success can be deceiving in the study of course design, and it likely took many generations for the component plants to develop into robust, reliable crops in order for all four to six plantings of the Norfolk Rotation to be reliably grown.

Some of the earliest examples of the Norfolk date to 1739 and 1751. Yet in these rotations from west Norfolk, wheat is succeeded by turnips, barley, and clover.[115] “Thereafter this sequence of cropping spread to the rest of the county, although strict adherence to the Norfolk four-course was rare,” writes Bruce Campbell in an article co-authored with Overton.[116] In these early examples, alternative crops were sometimes used, though it was most common to see oats and legumes as the derivations. Clover leys lasted for several years, and fallows were still used.[117]

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[113] Robert Allen, C. , "The Nitrogen Hypothesis and the English Agricultural Revolution: A Biological Analysis," *The Journal of Economic History* 68, no. 1 (2008): p. 197.
[114] William Amos, *The Theory and Practice of the Drill Husbandry: Founded Upon Philosophical Principles, and Confirmed by Experience* (S.l.: s.n., 1802), p. 194.
[115] M. S. Campbell Bruce and Overton Mark, "A New Perspective on Medieval and Early Modern Agriculture: Six Centuries of Norfolk Farming C.1250-C.1850," *Past & Present*, no. 141 (1993): p. 62-3.
[116] Ibid., p. 63.
[117] Ibid.

Indeed, in writing this chapter, I found that even just a few years prior in 1744, examples of course plantings were more likely to include rapeseed than clover. To offer just one example, In the April issue of *The Modern Husbandman; or, The Practice of Farming* William Ellis writes:

> …. By getting a crop of such barley, sooner than ordinary, off the ground, it gives a Farmer the opportunity to sow the same land with turnips, early enough to enjoy a full crop of them. Another reason is, that we can (if the land is proper for it) sow rape seed. A third is, that, by mowing off such a very early crop, we have an opportunity to plow the ground several times, for sowing wheat in the same in October following.[118]

Here the addition of clover would constitute a proper Norfolk Rotation with rape used in place of turnips.[119] Even if such an example evaded the data mining and key word searches, or is hiding elsewhere in the archives, it is clear that the more structured rotations of turnips, barley, clover, and wheat only became more common in the later part of the eighteenth century. However these designs emerge from earlier fledgling courses. The introduction of the crops thus signals the slow progression of the rotation design as an adaptable structure tested by time.

This is not how the story of a rapid agricultural revolution is usually told. Returning to our narrator in *Make Fruitful the Land*, it is the Norfolk Rotation that suddenly pulled England out of the Dark Ages thanks to the help of scientists and men of letters who revised the Three Field Rotation introduced 15 centuries ago by the Saxons. According to the narrator:

> Outside each village there were three great fields which were cultivated in strips by the people of the village. Each year one of the fields was planted with winter sown wheat; another grew spring corn, and other spring sown crops like peas or beans while the third field was left idle for the season to rest the soil and allow the weeds to be destroyed. Much better crops were obtained by this three field system, but it meant that one of the fields was wasted every year, and no winter food was grown for the animals.[120]

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[118] William Ellis, *The Modern Husbandman; or, the Practice of Farming. Containing the Months of April, May, and June.* , v. 4 vols., vol. v. 2 (London: Printed for, and sold by T. Osborne, and M. Cooper, 1744), p. 31.
[119] Ibid., p. 29.
[120] Annakin, "Make Fruitful the Land " 1:30-2:30 min.

According to the narrator, this was the only rotation known to farmers through the Middle Ages, and it only changed in the eighteenth century when elites introduced new crops and machines. As a result of new plants and methods, "… a new system of farming was evolved which came to be known as the Norfolk Four Course Rotation," says the narrator.[121] This model fits nicely with the nitrogen thesis, as the goal of the Norfolk was to put back in the land what was taken from it. Though Campbell and Overton entertain more complexity in their chronological study of six centuries of Norfolk Farming, they emphasize the importance of the Norfolk in increasing nitrogen. According to the authors, "reserves of nitrogen had been continually depleted for millennia," and it was the utilization of nitrogen-fixing legumes in the Norfolk Rotation combined with higher herd stock densities that saved yields as population pressures began to mount in the eighteenth century.[122]

Yet this narrative is complicated by the early introduction of *B. napus* for industry combined with its periodic debut in the proper Norfolk Rotation. It is the late introduction of clover and the even more delayed widespread introduction of the crop through rotation that fuels Campbell and Overton in arguing for an eighteenth century British Agricultural Revolution. In this model, the primary benefits of nitrogen fixation were not realized until much later in the eighteenth century when legumes were integrated as fodder during the widespread disbursal of the Norfolk Rotation. However when we shift the spotlight to the alternative crops used in the fodder cycles, we not only see alternative mechanisms of action such as soil pest suppression with *B. napus*, but a profound complexity of rotation design manifests in the derivations of the Norfolk Rotation.

121 Ibid., 3:50-4:30 min.
122 Bruce and Mark, "A New Perspective on Medieval and Early Modern Agriculture: Six Centuries of Norfolk Farming C.1250-C.1850," p. 89, 141.

As clover was understood to be a functional grass rather than as a member of its modern legume category, it may or may not have been as widespread as the Norfolk Rotation. As it turns out that categorical understanding of plants by their functional group was surprisingly important in rotation designs, clover was used as a grass for fodder and was thus often substituted with hay, rye, and rape as much as other legumes like Lucerne. While today we categorize clover as a legume, it was previously a design element that played the role of a fodder, green fallow crop, and feed in the Norfolk. But a number of plants could and did serve this same purpose. The role of *B. napus* as both a functional grass, root crop, and cash crop highlights the more profound innovation in design efficiency and diversification on a site-specific basis. In fact, as our study of rapeseed integration shows, the Norfolk Rotation was often six courses if not seven or eight. Similarly, the fact that every possible derivation of the Norfolk Rotation can be found in the archives suggests that wheat plantings increased through a slower and less progressive design revolution than a mere combining of new plants with new machines.

In conclusion, innovation did not occur rapidly and it cannot be measured by the introduction of each plant component into an age-old rotation system via a new schedule. The Norfolk was not simply the Saxon rotation on a privatized field and without the fallow; rather, it was a malleable design innovation that related abstract plant categories for the purpose of customization.

CHAPTER FIVE: Rapeseed for Manuring to Fight Pests and Improve Soils

I. Introduction

“Nitrogen, so important in the formation of the gluten in wheat… constitutes about 79 per cent of the atmosphere, but abundant as it is in the air, plants cannot absorb it by their leaves, nor in its simple form by the roots," wrote Levi Bartlett in his 1850 article *Manures—The Food of Plants*.[1] "For this purpose, it must be in a chemical combination with its equivalent of hydrogen, forming ammonia…” he continued. A decade earlier, J. von Liebig had introduced the idea that crop productivity was limited by whichever nutrient was in ‘relative minimum,’ but that among the limiting nutrients, nitrogen was the most common source of growth.[2] From this assumption, generations of agronomists came to define livestock manure as a fertilizer technology. Bartlett’s work marks this early mechanistic understanding. "Ammonia is generated in large quantities from stable and other rich manures while passing through the process of fermentation," he advised.[3] Motivated by the knowledge that ammonia created nutrient rich soils, farmers began to develop new approaches to collect and prepare precious manures. “Thousands are careful to save most of the solid part of the droppings of their cattle, while they take no means to save urine, which is vastly more rich in nitrogen than the dung…” wrote Bartlett.[4] To collect the urine from ten head of cattle, he spread barn floors with one bushel of fine dry charcoal and three quarts of ground plaster topped with hay. The manure was thrown under sheds each day to compost under a dry cover that kept out the rain and snow.

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[1] Levi Bartlett, "Manures—The Food of Plants—No. 4," *American Agriculturist* v. 9, no. v. 8 (08/1850). p. 243.
[2] B. M. S. Campbell, *English seigniorial agriculture, 1250-1450*, Cambridge studies in historical geography, (Cambridge ; New York: Cambridge University Press, 2000), p. 192.; N. Galloway James et al., "A chronology of human understanding of the nitrogen cycle," *Philosophical Transactions: Biological Sciences* 368, no. 1621 (2013), p. 2.
[3] Bartlett, "Manures—The Food of Plants—No. 4," p. 243.
[4] Bartlett, "Manures—The Food of Plants—No. 4," p. 243.

From such period examples, the historiography praises nitrogen as the link between the humble scrapings of the barn floor and the economic restructuring of the British economy during the Agricultural Revolution. While it was only in the late nineteenth century that the role of bacteria in nitrogen fixation was understood, and in the twentieth century that researchers discovered how rhizobia bacteria required a plant host to express the genes for fixation, the use of manure as fertilizer dates to antiquity.[5] However models of increased nitrogen from manuring focus on the eighteenth to mid-nineteenth centuries for the widespread integration of leguminous fodders with nodules on the roots that host nitrogen fixing rhizobia bacteria. New fodder integration sustained increases in herd size and supported larger manure contributions. Researchers like Enric Tello of the University of Barcelona and his colleagues relate the onset of the Agricultural Revolution to the regulation of soil temperature and thus microbial nitrogen mineralization during the Little Ice Age.[6] As the bacteria which fix and mineralize nitrogen are responsive to slight changes in temperature variation and perform best in rich soils, larger manure loads helped optimize conditions for nitrogen mineralization during years when temperatures slowed the metabolism of the soil microbiome and human populations increased.[7] Simply put, manure increased soil temperatures in cold months while cooling the earth in hot months. G. P. H. Chorley similarly related increased output per hectare during the Agricultural Revolution to nitrogen accumulation from foddering and animal manuring. He wrote "…it could be argued that an increase in the nitrogen supply (or in the efficiency of its utilization) was a

[5] James Galloway, N., Leach, Allison, M., Bleeker, Albert, Erisman, Jan Willem, "A chronology of human understanding of the nitrogen cycle," *Philosophical Transactions: Biological Sciences* 368, no. 1621 (2013); W.C. Lindemann and C.R. Glover, *Nitrogen Fixation by Legumes*, Department of Extension Plant Sciences, New Mexico State University (College of Agricultural, Consumer and Environmental Sciences, New Mexico State University, 2015); Edwin Broun Fred, Ira L. Baldwin, and Elizabeth McCoy, "Root Nodule Bacteria and Leguminous Plants," (2009).
[6] Enric Tello et al., "The Onset of the English Agricultural Revolution: Climate Factors and Soil Nutrients," (2017). p. 446-48, 57-60.
[7] Tello et al., "The Onset of the English Agricultural Revolution: Climate Factors and Soil Nutrients," p. 457-60.

necessary condition of the change in the pattern of cropping, that without one or the other... cereal yields would have fallen below the economic level."[8]

Yet if we more carefully explore period advise on manuring, it turns out that animal dung was only one of many inputs to the soil used to increase productivity during the long eighteenth century. *B. napus* serves as a particularly good case study because period actors recommended its cake and dust as an alternative to animal manure as well as to fight the soil pests that devoured crops. By focusing on period evidence of *B. napus* meal tillage for manuring, this chapter moves beyond the nitrogen thesis and the disproportionate emphasis placed on nitrogen fixing legumes in order to explore the historical importance of suppression of soil pathogens—a term that describes microorganisms like oomycetes that cause water molds, fungi that cause root rot, bacteria that cause blights, and the microscopic worms known as nematodes which eat plant roots and tubers. *B. napus* manure was used to fight the wireworm (Coleoptera: Elateridae) as well as various molds and rank soils that cannot be mapped with certainty to modern fungal and oomycota taxonomies.

B. napus was clearly used as a manure by the Scotsman Francis Blaikie, who penned *A Treatise on Mildew, and the Cultivation of Wheat, Including Hints on the Application of Lime, Chalk, Marl, Clay, Gypsum, &c.* Due to their popularity, many of Blaikie's works were printed as second and third editions during his lifetime. In the second edition printed in 1820 Blaikie writes:

[8] G. P. H. Chorley, "The Agricultural Revolution in Northern Europe, 1750-1880: Nitrogen, Legumes, and Crop Productivity," *The Economic History Review* v. 34, no. 1 (1981), p. 92.

> I would ask what good result can possibly be expected from the application of clay or marl without manure to exhausted light arable land. In mentioning manure, I do not confine the term to farm yard dung. It also applies to rape dust… It is true a plant of wheat may exist in a compound of earths alone, but it cannot flourish nor become productive without a specific quantity of manure.[9]

This demonstrates that the pulverized husks of *B. napus* left from the oil crushing press were considered to function much like animal manure when nurturing the soil for wheat. Blaikie tilled the meal left from *B. napus* oil milling into the earth as a manure in order to improve the soil—a tactic that demonstrates his innovative implementation of improvement plans on tenant farms. After moving to England, Blaikie managed the famous estate of Thomas Coke in Holkham, Norfolk. Though Coke gained fame as a pioneer of Lucern and father of the four course rotation, it is Blaikie's published pamphlets on convertible husbandry and manuring that link disbursal to the increased herd and field sizes that characterize agricultural progress in Norfolk.[10]

Similarly, in 1795 John Aiken published a short section on manures in *A Description of the Country from Thirty to Forty Miles Round Manchester*. He describes that "besides those in common use in other parts, the farmers employ ground bones, horn shavings, and rape dust."[11] Similarly, according to Robert Somerville and his 1795 *Outlines of the Fifteenth Chapter of the Proposed General Report from the Board of Agriculture on the Subject of Manures*:

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[9] Francis Blaikie, *A treatise on mildew, and the cultivation of wheat including hints on the application of lime, chalk, marl, clay, gypsum, &c. &c*, 2nd ed., enl. ed. (London: Printed for J. Harding, 1820), p. 31-32.

[10] R. A. C. Parker, "Coke of Norfolk and the Agrarian Revolution," *The Economic History Review* 8, no. 2 (1955); G. E. Mingay, "Blaikie, Francis (1771–1857), Agriculturist and Land Agent," in *Oxford Dictionary of National Biography* ed. Editors of the Oxford Dictionary of National Biography (Oxford University Press, 2004-09-23 2004).

[11] John Aikin, *A description of the country from thirty to forty miles round Manchester; ... The materials arranged, and the work composed by J. Aikin, M.D. Embellished and illustrated with seventy-three plates* (London: printed for John Stockdale, 1795), p. 95.

Table 5.1 *Key Dates in the Discovery of Nitrogen and its Role in Agriculture*

1772:	Carl Scheele, Henry Cavendish, Joseph Priestley, and others independently discovered nitrogen.
1774:	In 1774 Joseph Priestley discovered ammonia.
1784:	Claude Louis Berthollet found that ammonia was made out of the elements nitrogen and hydrogen.
1785:	Henry Cavendish produced HNO_3.
1823:	Johann Wolfgang Do˙bereiner produced ammonia using a platinum catalyst.
1836:	Jean-Baptiste Boussingault identified nitrogen as a nutrient for plants.
1838:	Boussingault concluded that legumes could fix nitrogen after the crops thrived in sterilized sand that lacked nitrogen.
1840:	Justus von Liebig showed that nutrients needed to be added to the soil to guarantee the next crop but believed that nitrogen came from precipitation.
1843:	John Bennet Laws and Joseph Henry Gilbert added ammonium sulfate to field crops and gained larger yields.
1856:	Jules Reiset recognized that decaying organic matter released nitrogen.
1880:	Hermann Hellriegel and Hermann Wilfarth discovered biological nitrogen fixation and proposed that root nodules supported nitrogen fixing microbes.
1908:	Fritz Haber synthesized ammonia from hydrogen and nitrogen with a process that could be scaled to the industrial level.
1913:	Carl Bosch performed Haber's ammonia synthesis on an industrial scale.
1970s:	Synthetic nitrogen creation surpassed nitrogen fixation.
2011:	There were 540 reported dead zones from eutrophication and hypoxic water conditions partially caused by nitrogen runoff from agricultural fertilizers.[12]

[12] James et al., "A chronology of human understanding of the nitrogen cycle," p. 2-5.

> Rape cakes has of late years been much used as a manure, both upon fallows for wheat and barley, and for turnip crops. The ordinary way of preparing it is by breaking it with a mill, and sowing it by hand before the fallows receive the last ploughing; in this way it has been of considerable service.[13]

For a good compost for all soil types, Somerville recommends mixing six parts of rape dust and one of lime at least ten days prior to use, and turning the mixture once each day. This illustrates that *B. napus* was versatile as a manure.

To offer one last introduction to *B. napus* manuring, we see rapecake ground into a fine powder used to control wireworm in the monthly articles published during the early nineteenth century in *The Farmer's Almanac and Calendar*.[14] According to an Oct 1843 article titled *Manures and their Prices in London,* rape dust cost seven pounds per ton and "This, in common with all fertilizers of an oily nature, is much more decided in its effects in wet than in dry seasons… It is noxious to the wireworm and other predatory vermin of the farmers crops."[15] Such complaints over the wireworm larvae of click beetles (Coleoptera: Elateridae) echo modern frustrations with the pest, which ravages fields in every part of the world where food is grown.[16] Damage to crops in Europe and North America are often attributed to one of the 200 species of

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[13] John Aikin, *A description of the country from thirty to forty miles round Manchester: containing its geography, natural and civil; principal productions; river and canal navigations; a particular account of its towns and chief villages; their history, population, commerce, and manufactures; buildings, government, &c*, ed. John Stockdale (London: Printed for John Stockdale, 1795), p. 38.

[14] There are more than 9,000 species of wireworm documented around the world, though damages to crops in Europe and North America are often attributed to one of the 200 species of Agriotes Eschscholtz. In the Pacific Northwest of America, Limonius canus Leconte and other species in the same genus are also implicated in severe crop damage. Cuthbert W. Johnson and William Shaw, "Manures and Their Prices in London," *The Farmer's Almanac and Calendar* v. 4 (October 1843); Fanny Barsics, Eric Haubruge, and François Verheggen, "Wireworms' Management: An Overview of the Existing Methods, with Particular Regards to Agriotes spp. (Coleoptera: Elateridae); Gestion des taupins : Bilan des Stratégies de Lutte Intégrée, avec un regard particulier sur Agriotes spp. (Coleoptera: Elateridae)," (2013).

[15] Johnson and Shaw, "Manures and Their Prices in London," p. 93.

[16] Fanny Barsics, Eric Haubruge, and François Verheggen, "Wireworms' Management: An Overview of the Existing Methods, with Particular Regards to Agriotes Spp. (Coleoptera: Elateridae), *Insects*, 4, (2013), p. 117-18.

Agriotes Eschscholtz, and even today there is no effective treatment to combat Agriotes once the symptoms of damage manifest.[17]

This suggests that period farmers considered a more diverse array of manuring and fertilizer applications than the historians of nitrogen improvement have described. Nitrogen residues in farmyard manure do not become immediately available to crops. Mineralization rates can also vary more between sites than with temperature. From this, both Chorley and Tello warn that the accumulation of bioavailable nitrogen from manuring may have been slow over time.[18] Thus, attempts to delve into the mechanisms by which nitrogen from fodder and manure improved soils only raise as many questions as they attempt to answer about the environmental basis for economic restructuring. In contrast, period sources describe a more diverse range of soil improvement mechanisms.

Though modern historians have yet to revise concepts of the British Agricultural Revolution based on our modern understandings of pest suppression, I would like to suggest that oil seed species might have triggered" innate plant immune defenses, increased beneficial bacteria, and released pest-killing isothiocyanates from both the plant, the crushed plant components used as a green manure, and the crushed seed meal left from the oil press.[19] Let me turn briefly to some modern examples of how pest suppression operates." USDA researcher

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[17] Fanny Barsics, Eric Haubruge, and François Verheggen, "Wireworms' Management: An Overview of the Existing Methods, with Particular Regards to Agriotes Spp. (Coleoptera: Elateridae), *Insects*, 4, (2013) Fanny Barsics, Eric Haubruge, and François Verheggen, "Wireworms' Management: An Overview of the Existing Methods, with Particular Regards to Agriotes Spp. (Coleoptera: Elateridae), *Insects*, 4, (2013), p. 117-19.
[18] Chorley, "The Agricultural Revolution in Northern Europe, 1750-1880: Nitrogen, Legumes, and Crop Productivity," p. 76; Tello et al., "The Onset of the English Agricultural Revolution: Climate Factors and Soil Nutrients," p. 472.
[19] D. M. N. Weerakoon et al., "Long-term suppression of Pythium abappressorium induced by Brassica juncea seed meal amendment is biologically mediated," *Soil Biology and Biochemistry* 51 (08/01/2012); C. L. Reardon, S. L. Strauss, and M. Mazzola, "Changes in available nitrogen and nematode abundance in response to Brassica seed meal amendment of orchard soil," *Soil biology & biochemistry* 57 (01/01/2013); Nikoletta Ntalli and Pierluigi Caboni, "A review of isothiocyanates biofumigation activity on plant parasitic nematodes," *Phytochemistry Reviews* 16, no. 5 (10/2017).

Leslie Elberson showed a dose-dependent mortality curve after treating soils infested with wireworm *Limonius californicus* (*L. californicus*), which attacks potatoes, sugar beets, and some grains in the US Pacific Northwest.[20] After collecting wireworm from an alfalfa field, the pests were weighed and placed in plastic vials filled with silt loam soil. Germinated wheat seeds were added for food. Defatted rapeseed meal from the industrial oilseed press was compared to control groups with deactivated meal soaked in water and vented after addition to the soil. No mortality was observed in this control or in vials of soil left untreated. But as the concentration of *B. napus* increased from 41.7 to 158.1, 283.1, and finally 500 g/kg, *L. californicus* mortality jumped from 15 to 60, 75, and 95%, respectively. At more plausible rates of 65.9 and 88.9 g/kg, mortality was 40%.[21] Other studies have tested *B. napus* as well as other Brassica oilseeds to compare plant treatments against chemical applications of Telone and Chloropicrin. The success of Brassica treatments is attributed to the glucosinolate compounds that give plants in the mustard family a spicy flavor and break down upon contact with water into pest-killing isothiocyanate fumes.[22] The meals crushed from Brassica oilseeds have also shown significant mortality of parasitic nematodes, which differ taxonomically from wireworm and cannot be easily seen without a microscope due to their small size of 15-16 um. In contrast, chopped fresh

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[20] L. R. Elberson et al., "Toxicity of rapeseed meal-amended soil to wireworms, Limonius californicus (Coleoptera: Elateridae)," *Journal of Agricultural and Urban Entomology* 13, no. 4 (01/01/1996), p. 327.

[21] Elberson et al., "Toxicity of rapeseed meal-amended soil to wireworms, Limonius californicus (Coleoptera: Elateridae)," p. 324-6.

[22] Ntalli and Caboni, "A review of isothiocyanates biofumigation activity on plant parasitic nematodes," ;Clarissa Potgieter, Misha De Beer, and Sarina Claassens, "The effect of canola (Brassica napus) as a biofumigant on soil microbial communities and plant vitality: a pot study," (2013); M. Mazzola et al., "Mechanism of Action and Efficacy of Seed Meal-Induced Pathogen Suppression Differ in a Brassicaceae Species and Time-Dependent Manner," (2007).



5.1 *Rapeseed Cake and Meal.* The glucosinolate compounds that make wasabi spicy are found in the plants and seeds of the mustard family. Released upon contact with water, glucosinolates break down into isothiocyanate, which kills pathogens and pests like root rot and wireworms. Top left: Wasabi, Tom Magliery, © flicker;[23] Bottom left: Dry, crushed rapeseed meal with oil extracted, Farm Fuel Inc.; Top Right: Rapeseed cake crushed from the oil press with some oil remaining.[24]

[23] Tom Magliery, *Wasabi* 2006.
[24] Indiamart, *Rapeseed Oil Cake,* 2020.

plants used as a green manure also contain glucosinolates but are less consistently effective as a treatment.[25]

B. napus has also been tested as a treatment for root rot and other soil diseases. In one of the more creative studies, Mike Cohen of Sonoma State University split the roots of an apple tree seedling between two pots; in one container he introduced the root rot pathogen *Rhizoctonia Solani* (*R. solani*), and in the other he used disease-free soil.[26] Rapeseed meal was incorporated into the uncontaminated soil in order to test its role in triggering favorable chemical interactions between the root and soil microbes. Could introducing rapeseed to clean soil trigger plant defenses that would help fight disease in the adjacent, but restricted, contaminated pot? While the rapeseed never came in contact with disease organisms, it reduced root rot in the disease-infested container by about 50 percent relative to control groups grown without the treatment. Cohen wrote that the entire plant benefited from the rapeseed treatment even though only half of the roots were exposed—perhaps due to the fostering of beneficial bacteria in the clean soil.

As to the molecular mechanism of pathogen suppression, helpful bacteria like Streptomyces can trigger plant defenses by inducing the jasmonic acid pathway—a hormonal signaling system that helps plants suppress soil molds, bacteria, and predatory microscopic nematodes. Past studies have shown an increase of Streptomyces in soil treated with rapeseed, and Cohen similarly showed 10-times as many *Streptomyces* bacteria in soils amended by rapeseed meal. Results were later confirmed with field trials. Field experiments conducted on farms along the Central Coast of California have sometimes shown 50% higher yields of cash

[25] Fanny Barsics, Eric Haubruge, and François Verheggen, "Wireworms' Management: An Overview of the Existing Methods, with Particular Regards to Agriotes Spp. (Coleoptera: Elateridae), *Insects*, 4, (2013), p. 130; Potgieter, De Beer, and Claassens, "The effect of canola (Brassica napus) as a biofumigant on soil microbial communities and plant vitality: a pot study."
[26] M. Mark, M. F. Cohen, and U. A. Tree, "Suppression of Rhizoctonia Root Rot By Streptomyces in Brassica Seed Meal-Amended Soil " (2005).

crops like strawberries when rapeseed meal was used in place of broad-spectrum chemicals like methyl bromide—a staple in the American berry and tomato industries still used to kill wireworms and molds despite phase-outs in most European countries.[27] Though the site-specific nature of agriculture means that findings are rarely repeated between fields, and attempts to reconstruct outcomes in eighteenth-century soils would be even more dubious, it is likely that *B. napus* offered a similar range of potential environmental impacts to historical soils. As our knowledge of *B. napus* mechanisms continue to develop, the historical importance of the meal may become better understood. Eighteenth-century manuring instructions also offer a reservoir of design details that might be helpful for modern farmers who have used the cake and meal from Brassica oilseed crushing for soil born pest control.

I begin this chapter by exploring examples of *B. napus* manuring for agricultural improvement in the long eighteenth century to make a case for a revisionist manure chronology. The adoption of *B. napus* meal tillage in early to mid-eighteenth-century points to a chronology of improvement that began at least 100 years prior to the early to mid-nineteenth century dates of onset so often offered for the British Agricultural Revolution. Second, I explore uses of *B. napus* for soil pathogen and pest suppression. Examples are fewer and date to the early to late nineteenth century, perhaps suggesting that a robust *B. napus* manuring technique supported the development of pest control strategies. While farmers understood the benefits of *B. napus* as a manure as early as the seventeenth century, it was in the period from 1730 to 1800 that the cake and dust became frequently recommended as a tillage treatment. Around this time, the plant became known as resistant to molds and worms. It was not until the end of the eighteenth and

[27] M. Mazzola "Potential of Biofumigation for Soilborne Pest Control in Strawberry;" M. F. Cohen and M. Mazzola, "A reason to be optimistic about biodiesel: seed meal as a valuable soil amendment" (2004); Ntalli and Caboni, "A review of isothiocyanates biofumigation activity on plant parasitic nematodes."

early nineteenth century that that the meal thought most potent by modern farmers became used to fight a range of pests. To illustrate these earlier plantings for pathogen and pest control, I offer examples of the many uses of *B. napus* to curtail rank soils, fight wireworm, and control pests. Finally, I delve into the rate of application and importance of creating oil-rich manures in the development of milling practices in order to consider the integration of industrial oil production and manuring innovation. Examples from the later part of the eighteenth century show that meal was purchased for use as a manure and also crushed on site by local farmers, though anecdotal archival evidence suggests it may also have been distributed from industrial mills in bags.

These cradle-to-cradle designs highlight the sophistication of the period integrated farming practices. *B. napus* cake and meal were byproducts from oilseed milling yet also served as inputs into a second system of crop production. In the production pipeline, *B. napus* entered the oil press as seed and then re-entered the crop field as manure. Seed was planted for both fodder and soil improvement, and these two systems occurred simultaneously as the stems reshot after grazing and turned to seed, all while improving soils. The period case study of *B. napus* thus illustrates the meaning of the mantra shared by modern green designers: "make zero waste."[28] Compost manures are a solution because they integrate organic byproducts back into the system of food production. In the eighteenth century this design was embraced as lived experience. In fact, there is little evidence that eighteenth-century actors considered *B. napus* cake and meal to be wastes. Francis Michael Longstreth Thompson was incorrect when wrote that "…sizeable quantities of [rapecake] residues must have been available for a very long time;

[28] M.L. Franco-García, J.C. Carpio-Aguilar, and H. Bressers, *Towards Zero Waste: Circular Economy Boost, Waste to Resources* (Springer International Publishing, 2018).

but for a very long time they were apparently regarded as worthless waste products."[29] Meals from the oil press did not rot or compost in trash heaps because systems of manuring were intentionally designed to increase rural production. *B. napus* manure is not the typical case study of an eighteenth century crop, but it is a unique example of the integrative nature of period improvement designs that minimized waste through utilization. This is not to say that eighteenth-century farmers indiscriminately put all waste back into the soil. Rather systems were designed to create quality outputs for multiple uses. Even if early modern farmers did not understand the full range of modern mechanisms and *B. napus* did not appear on every farm, the widespread application of meals as manures was known to have important environmental impacts on the very soils that suffered the strains of intensified production to support a growing industrial sector. Even if the environmental benefits of soil disease suppression from *B. napus* meal tillage were localized and gentle, they likely had an economically important environmental impact.

II. An Early Chronology of the "Second Great Agricultural Revolution"

There were three agricultural revolutions in England, and the second was "a matter of bones and of rape cakes," wrote Francis Michael Longstreth Thompson in his 1968 article *The Second Agricultural Revolution, 1815-1880*.[30] Thompson was the first to write in depth about rapeseed, and as Thirsk does not consider the crop in the context of the British Agricultural Revolution, his study remains the only serious consideration of the crop's role in eighteenth century economic restructuring. His research points to the importance of the meal, cake, and

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[29] F. M. L. Thompson, "The Second Agricultural Revolution, 1815-1880," *The Economic History Review* 21, no. 1 (1968), p. 66.
[30] Thompson, "The Second Agricultural Revolution, 1815-1880," p. 66.

dust as a manure, and this section builds on his work by illustrating that *B. napus* may have become important nearly 100 years earlier than Thompson suggested.

In keeping with the classic models developed by Arnold Toynbee and R. E. Prothero, Thompson believed that seed drills, iron ploughing, the Norfolk Rotation, and clover were most prevalent at a broad geographic scale by the late eighteenth century and early to mid-nineteenth centuries, and Britain had largely completed its First Great Agricultural Revolution characterized by these classic technologies by 1815. The farming sector then entered a second, later phase of development characterized by seed meal tillage and manuring with rapeseed and flax cakes. "By the time of the French Wars, therefore, the oilseed cakes were well on their way to upgrading their status from that of wastes to that of useful industrial byproducts," wrote Thompson.[31] The Second Agricultural Revolution was characterized by the plant stocks, seed meals, and residues tilled into the earth to benefit the soil, and during this phase rapeseed dust became a co-product made along with oil. The third revolution involved tractors and motors and began in 1914, while a possible fourth phase later in the twentieth century consolidated animals into factory farms with external feedstock inputs.

While Thompson's work is cited by Mark Overton and other leading historians, and his work on the Second Agricultural Revolution confirms my thesis that *B. napus* meal technology functioned as a form of agricultural improvement, his larger chronological model has never become widely popularized and the role of the Brassica species in agricultural innovation and economic restructuring remains largely unknown. Other historians have largely forgotten the Brassicas, and Thompson falls short of a primary-source analysis of period manuscripts. Instead, he largely relies upon secondary evidence compiled by WH Brace in *History of Seed Crushing in*

[31] Thompson "The Second Agricultural Revolution, 1815-1880."

Great Britain.[32] Brace, in turn, focuses on the nineteenth century disbursal of seed and bone crushing mills, but narrows his chronological study to the 1815-1880 period. Brace worked as a miller and published as an industry historian. His bibliography includes a scant one page of sources for a book that spans about 170 typed pages. While Brace clearly describes trends in the seventeenth and eighteenth century, his earliest source is from 1858. Most of his sources date to the early twentieth century. In short, neither Thompson nor Brace spent much time at the archives before developing their models. Thus, the chronology Thompson establishes for the second revolution defined by manures limits the major contributions of Brassica species to the early and mid-nineteenth century without appropriate investigation of the long, early history of Brassica innovation in Britain. Thompson's 1815 date for the onset of an agricultural revolution of rapeseed manuring and other manures is an artifact of his secondary sources.[33]

To the contrary, *B. napus* meal manuring may have begun as early as its large-scale industrial introduction in the early seventeenth century. I was surprised to discover at the Oxford Bodleian Library special collections that in 1634 Augustine Mathewes published a book of directions for making a manure from rapeseed cake crushed from rapeseed at the oil mill. The recipe appears in a pamphlet titled *A Direction to the Husbandman, in a New, Cheape, and Easie way of Fertiling, and Inriching Areable Grounds, by a mixture of certaine Native Materialls, in small quantities with the seed to sow, and strowing the same upon the Ground sowed*, and instructions begin with the mixing of rape oil with corne seed to moisten and join the "Flower or powders." The full recipe is complex:

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[32] Harold Witty Autor Brace, *History of seed crushing in Great Britain* (London: Land Books Limited, 1960).
[33] Thompson "The Second Agricultural Revolution, 1815-1880," p. 65.

> Then take one Quart of the Flower of Beanes, being first Maulted. One quart of the powder of Rapeseede Cakes after the Oyle is pressed out; One quart of burnt Lyme new from the Kilne, quenched with Vrine, and sifted; or so much of each of them in equally parts, as may well cover and encompasse the said Seede.[34]

Hand written marginalia on the side of the printed paragraph recommend the addition of one-quart dried pigeons' dung. This illustrates that complex recipes for manuring emerged in the literature just years after English clothier Benedict Webbe obtained a 1624 King James I edict granting monopoly rights to the rape milling technology he imported from France.[35] *A Direction to the Husbandman* begins with a letter dedicated to the true patriot Webbe and references "Letters Pattents" for manuring awarded to Charles Mowet, Edward Keeling, and Nathanael Waterhouse Gent. It claims such patents omitted the proportions as well as the manner of mixture and application of manure, and delivers this knowledge to the tenant farmer. The pamphlet describes its intention to offer full direction to the husbandman "in the use, exercise, and practice of the said new Invention."[36]

Perhaps the 1634 pamphlet was a rebellious patent buster as the opening letter is anonymously signed "Trie and Trust." Augustine Mathewes is named printer, but the authorship of the work remains unknown.[37] An 1813 tract published in the *Harleian Miscellany* attributes the manure recipe to Augustine Mathewes. However the 1634 pamphlet does not name any

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[34] Augustine Mathewes, *A Direction to the Husbandman, in a New, Cheape, and Easie way of Fertiling, and Inriching Areable Grounds, by a mixture of certaine Native Materialls, in small quantities with the seed to sow, and strowing the same upon the Ground sowed*, 1634, Pre-1701 Weston Closed Stack, Ashmolean, ASHM 2512435, University of Oxford, Aleph System Number 014377520, p. B-B2.
[35] Sovereign England and Wales and King of England James I, *James, by the grace of God, king of England, Scotland, France, and Ireland, defender of the faith, &c. to all to whome these presents shall come, greeting whereas our welbeloued subiect, Benedict Webbe, of Kingeswood, clothier, hauing in his trauell, obserued a kinde of oyle to bee made of rape-seede*, December 18 1624, [London : F. Kingston Ann Arbor, MI Oxford (UK) : Text Creation Partnership].
[36] Mathewes, *A Direction to the Husbandman, in a New, Cheape, and Easie way of Fertiling, and Inriching Areable Grounds, by a mixture of certaine Native Materialls, in small quantities with the seed to sow, and strowing the same upon the Ground sowed*, p. B-C.
[37] The Oxford Solo catalogue attributes the work to Augustine Mathewes, and he is named as publisher in the pamphlet.

author who might be blamed for circulating a mystery of the craft.[38] Or perhaps in the spirit of the 1623 Statute of Monopolies, which prevented patents from infringing on self-sufficient, local production, the writing may have served as a legitimate transfer of knowledge to non-competing husbandmen who lacked commercial interests.

Regardless of the debates over authorship and the political implications of the manuring recipe, we know from the 1634 publication date that rapeseed was recommended as a manure within about a decade after the crop was introduced to England at the industrial scale for oil crushing.[39] Though my research focuses on works from the eighteenth century due to the greater preponderance of surviving archival resources and the importance of this period to the historiography of the British Agricultural Revolution, it is clear from the discovery of *A Direction to the Husbandman* that rapeseed manuring technology was at least nascent by the early seventeenth century. Thompson cites 1716 as the first date of the reported use of rapeseed cake for improvement, though his example suggests crushed seed was used in Northamptonshire as cattle feed rather than as a manure.[40] He cites similar uses in Lincolnshire in 1725, though his examples depict the burning of cake as fuel by villagers. This use of rapeseed as fuel limited the availability of cattle feed.[41] Regardless of these early eighteenth-century uses, Thompson argues that bone meal manures and rapeseed cake fertilizers were not employed on a significant scale until well after 1815. Only in the 1816 to 1830 period did rapeseed become well regarded as a manure, and even then, it was likely decades before the technology was widely adopted.[42]

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[38] W. Oldys, T. Park, and E.H.E. Oxford, *The Harleian Miscellany: A Collection of Scarce, Curious, and Entertaining Pamphlets and Tracts, as Well in Manuscript as in Print* (John White, and John Murray ... and John Harding, 1813), p. 395.
[39] England and Wales and James I, *James, by the grace of God, king of England, Scotland, France, and Ireland, defender of the faith, & c. to all to whome these presents shall come, greeting whereas our welbeloued subiect, Benedict Webbe, of Kingeswood, clothier, hauing in his trauell, obserued a kinde of oyle to bee made of rape-seede*;
[40] Thompson, "The Second Agricultural Revolution, 1815-1880," p. 66.
[41] Ibid.
[42] Thompson, "The Second Agricultural Revolution, 1815-1880," p. 64-67.

In sharp contrast, Richard Bradley's 1727 *A Complete Body of Husbandry* shows that oil cakes functioned as a much-used manuring staple in parts of Cambridgeshire and the north part of Essex. "That is, the cakes of lint-seed, rape-seed, &c. after the oil has been pressed out of them at the mills, these cakes are then ground to powder in mills, and strewed upon the ground and ploughed in," wrote Bradley.[43] He clearly recommended the improvement's profitability, though also described the problem of soil exhaustion as if the application of rape cake gave rise to such vigorous crops "that the very heart of the ground is destroyed." Rape cakes brought up "luxuriant crops" and were helpful to vegetation and the growth of plants. But to use this technology more than one year, Bradley recommends reducing the vigor of the cake by mixing it with fine earth, sand, or malt dust. This will "preserve the land in tolerable strength" while bringing up crops of value.[44] It is important that Bradley recognizes the importance of rapeseed cake as a soil improvement and specifically describes the milling of the cake and its application to soils to increase land value and preserve soil fecundity. Even in the early eighteenth century, nearly a full century before Thompson's manure revolution began, farmers like Bradbury not only integrated the technology but recommended complex schematics such as milling and combinations with other manures. This knowledge of the technology's potential to cause soil exhaustion and his recommendation of dilution for application reflect a conceptual understanding of the mechanisms that likely evolved through trial and error over time and may be useful to modern farmers.

[43] Richard Bradley, *A complete body of husbandry; collected from the practice and experience of the most considerable farmers in Britain. ... Adorn'd with cuts. By R. Bradley* (London: printed for James Woodman, and David Lyon, 1727), p. 95.
[44] Bradley, *A complete body of husbandry; collected from the practice and experience of the most considerable farmers in Britain. ... Adorn'd with cuts. By R. Bradley*, p. 95-6.

In the 1733 *Chiltern and Vale Farming Explained, According to the Latest Improvements*, William Ellis offers detailed description of *B. napus* seed meal tillage. He writes:

> Hogs hair and coney clippings are very good dressings for the light soils harroughed in with wheat, rye, or barley, so are oil cakes of rapeseed, etc, that are now used much about Luton in Bedfordshire, which they chop small or grind, and plough or harrough into a great profit.[45]

Ellis notes that "cakes of rape-seed" served as a primary source of general manure in the area and had become more frequently used. Farmers and neighbors had equally contributed to purchase twenty twelve-bushel sacks to share. Ellis describes how his neighbors carried the sacks to London, where they filled them with rapeseed and other manures for use on the farm.

Thomas Salmon similarly wrote of an abundance of rapeseed meal tillage while explaining the customs of Cambridge in 1748 in *The Foreigner's Companion*. According to Salmon: "Quantities of oil, made of flax-seed, cole-seed, hemp and other seeds, ground or press'd by the numerous mills in the Isle of Ely, are brought up this River also; and the cakes, after the oil is press'd out, afford the farmer an excellent manure to improve his grounds."[46] Here Salmon referenced coleseed, which is often used as another name for rapeseed. Oilseed manures were frequently referenced in the many works penned by Ellis. In the third volume of *The Modern Husbandman* he described the use of two seven-foot diameter stones to crush the seeds and offered a suggestion for the remaining dust or powder. Ellis writes:

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[45] William Ellis, *Chiltern and vale farming explained : according to the latest improvements*, ed. William ca Ellis (London: Printed for the author William Ellis of Little-Gaddesden near Hemstead in Hertfordshire. And sold by W. Meadows ... H. Walthoe ... J. Parker ... 1733), p. 398-9.

[46] Thomas Salmon, *The foreigner's companion through the Universities of Cambridge and Oxford, and the adjacent counties. ... By Mr. Salmon* (London: printed for William Owen. And sold by the booksellers in Cambridge, Oxford, and London, 1748), p. 11.

> …if the Manure of Peat-ashes-Malt-dust; Oil-cake Powder or such like, be sown over all the Seed, as soon as it is harrowed in, it may prove of great service, and force on a plentiful crop of all the three several Sorts of Vegetables, Time enough for the Farmer's Profit, and which will be the more improved, if the Sheep are folded on the same Ground...[47]

These works are surprisingly detailed in both their descriptions of oilseed manuring and in their specific recommendations of rapeseed cake and dust for this purpose. Even as early as the eighteenth century we can find multiple examples of manuring with rapeseed throughout the improvement literature.

The design details similarly illustrate an early integration of *B. napus* manure into complex systems of production. Ellis recommended folding sheep on the same ground manured by oil cake, which increased fecundity, while Bradbury mixed rape cake with soil to dilute its potency in order to prevent soil exhaustion. While we still do not know if an excess of *B. napus* manure might over-saturate the soils with chemical signals, this sort of a problem might weaken the plant innate immune response or limit the proliferation of beneficial microbes. However the strategy developed by Ellis to mitigate exhaustion suggests that the technology was so widely integrated that knowledge of the range of harms and benefits was also understood. Rapeseed manure was clearly an industrial product of milling operations. Manure was shipped up river and sold to farmers in large sacks. The treatment was integrated into soils also treated with hogs hair and clippings. Due to success of these designs, rapeseed manuring become more frequently documented as the century continued.

Richard North described an established distribution infrastructure in the 1759 *An Account of the Different Kinds of Grasses Propagated in England, for the Improvement of Corn and*

[47] William Ellis, *The Modern Husbandman, or, the Practice of Farming. Containing the Months of January, February, and March*, 4 vols., vol. v. 3 (London: Printed for, and sold by T. Osborne and M. Cooper, 1744), p. 48.

Pasture Lands, Lawns and Walks. He described how rape mills in different counties sold rape cakes or oil cakes for about a shilling a bushel.

> Rape cakes or oil cakes are the hulls of seed after the oil is pressed out. They are sold at the rape mills in different countries: In some places they will cost about a shilling a bushel, in others not so much. They are used to manure wheat or barley. Some sow them upon wheat just as it is harrowed in, and others turn it in by the last. But I take the first Method to be best because Winter Rains will easily cause this small oily manure [to] sink into the Ground.[48]

North recommended grinding the cake from the mill or otherwise breaking up pieces before manuring. He described how farmers prepared the soil for rape manuring with paring and burning. These complexities of design varied from site to site but were common in his region.

In 1764, *A Letter to the Editors, on the Culture of Coleseed, & c* was published in the *Museum Rusticum et commerciale* or the *Select Papers on Agriculture, Commerce, Arts, and Manufactures to Describe Local Land Improvement in the Borders of Berks*. Signed by "A Country Rector" on March 1, the letter uses the terms "cole-seed" and "rape-seed" interchangeably and details the many uses of the crop. It was used to feed bullocks, wethers, ewes, and cows and sometimes left to stand for a crop of seed. But most importantly, it was tilled into the land for manure. A footnote after the description offers further explanation: "Of this seed is made the rape-oil which purpose and amazing quantity is cultivated in some parts of England: and the cakes, after the oil is expressed, are used for feeding oxen and manuring land."[49] Here we can add another branch to the production chain—rapeseed cake served as feed as well as manure while the plant provided fodder and supplied oil mills. The robust nature of

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[48] Richard North, *An account of the different kinds of grasses propagated in England, for the improvement of corn and pasture lands, lawns and walks with many useful directions for sowing them, manuring, &c. ... and the best directions for raising turnips, rape, cabbage, &c. ... also an account of the manures ... with directions for trench-plowing : likewise an account of the sound-growing Norfolk-Willow : with directions for propagating it to great advantage* (London: Printed by W. Prat, 1759), p. 29.

[49] Royal Society of Arts, *Museum Rusticum Et Commerciale: Or, Select Papers on Agriculture, Commerce, Arts, and Manufactures* (R. Davis, 1764), p. 2.

this design allowed farmers to integrate *B. napus* into multiple rotation cycles and herd grazing strategies.

By the mid-eighteenth century, rapeseed had also become part of a culture of agricultural experimentation. Field trials were not only conducted by gentleman farmers, but implemented by clergy and tenant farmers to test the use of rape cake as a manure, suggesting that the technology was well integrated as an improvement option. In 1764 John Randall outlined a complex schematic experiment in which "unrolled" fields were compared to soils "rolled as usual," a description that likely references the use of an agricultural roller tool to flatten land or break up large clumps of soil after ploughing. To his test soils Randall added "the usual quantity of pigeon's dung, rape dust, or soot, all very well spread over the ground, and harrow'd in the seed" by throwing the compost treatments over the ground by hand. After planting and harvesting, Randall observed a qualitative difference between the test groups, though he does not give much detail and suggests that outcomes varied from site to site. Randal recommended the use of alternative manures to other farmers and hoped that experimentation might allow the average farmer to choose the best soil treatments for their location.[50] The narrative account of this experiment was published in Randall's book *The Semi-Virgillian Husbandry, Deduced from Various Experiments: or, an Essay Towards a New Course of National Farming, Formed from the Defects*. Though Randall did not clarify whether rape or other manures were more productive, his results were generally favorable. This spirit of scientific agriculture was similarly expressed by Arthur Young when he wrote "The only object I have ever had in matters

[50] John Randall, *The semi-virgilian husbandry, deduced from various experiments, or, An essay towards a new course of national farming, formed from the defects, losses and disappointments, of the old and new husbandry ... [microform] : with the philosophy of argriculture : exhibiting, at large, the nutritive principles derived from the atmosphere, in a rotation of nature, from their being exhaled, to their descent into the pores of the soil ...*, (London: Printed for B. Law, Thomas Field, and John Wilkie, 1764), p. 59.

of agriculture, is experiment."[51] Young focused on planting technology to estimate the costs of farm labour per acre of feed crop produced, and his June 1770 tribute to scientific agriculture echoed the dedication of an entire generation of rapeseed growers.

In these early experiments, farmers compared rapeseed cake to other manures and tested the best seasons for planting, the number of ploughings, and the practice of harrowing. As one of many alternatives to animal dung, rapeseed is understood according to the mechanisms underlying manure improvement. Because of its oil content, rape dust and cake were added to and sometimes used in place of train oil (also known as whale oil from the blubber of whales) in order to finish mixtures of pot ash, lime, and sand. As the oils in compost were thought to resemble the natural food of plants but could also be too strong, the goal was to select for manure ingredients that supported fermentation. Rape dust was thought to support this fermentation and attenuate the oils while also contributing oils to the soil. An article published in 1769 in *The Monthly Review* recommends "The use of rape-dust, soot, horn shavings, and woolen rags, take off that objection, and at the same time confirm the theory upon which the above compost is founded."[52] This suggests that crushed rapeseed was used as a manure at least by the mid-eighteenth century.

In the July 23, 1773 edition of the *York Chronicle* nestled between a debate over the debasing of gold currency and an account of a man found dead after falling from his horse, a brief report appeared of a "most singular and judicious experiment" made of rape dust by an anonymous occupier of some lands between Ferry-bridge and Doncaster. The husbandman fixed a board to describe which part of the field was manured with rape dust, pidgeons dung, and

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[51] Arthur Young, *Essays on the Management of Hogs and the Culture of Coleseed, Including Experiments*, ed. Arts Society of, 2nd ed. with additions. ed. (London: Printed for W. Nicoll, 1770), p. 86.
[52] R. Griffiths and G.E. Griffiths, *The Monthly Review* (R. Griffiths, 1769), p. 475.

“Varon Van Haak’s compost.” “At present the pidgeons dung looks best; tire rape dust next, and the Baron’s compost much the worst,” reported the Chronicle, which encourages the agricultural societies established for improvement to recommend this mode of instruction to their tenants. In *The Farmer’s Director* Thomas Bowden similarly reported on the importance of the small size of manure granules or clumps. Published in 1776, the work explored how “many different things are made use of as manure..,” including “plants of all kinds ploughed into the land while green and in sap as clover, pease, buckwheat, and others which make good dressings for land, and the parts of plants as saw dust, bark, leaves, malt dust, rape cakes, sea shells, sea weeds, and others;”[53] These were ploughed into the land with mixtures of soil, but not until the size of the clumps had been made fine by working the manure. This level of detailed testing of manuring applications and the size of the clumps lacks rigor by modern standards, but it clearly puts *B. napus* meal in the same category as animal manure many decades before Thompson believed the British Agricultural Revolution began to harness such technology.

The abundance of manuring examples continues into the final decades of the eighteenth century. David Young of Perth wrote in the 1788 *Agriculture, the Primary Interest of Great Britain*, that while old grass would not require any dung, it was best for farmers who choose to apply dung to treat the manure as a top dressing “with either lint-seed or rape dust, salt, soot, pigeon, sheep, or goat dung, wood, or good peat ashes, harrowed in with the crop when sown.”[54] In 1793 John Spurrier documented manuring with rapeseed cake in Cambridgeshire and Northamptonshire when he wrote “…several make use of rape-canes, ground at the oil mills into

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[53] Thomas Bowden, *The Farmer’s Director; or, a Compendium of English Husbandry ... Also an appendix. Containing General Observations and Directions on Various Subjects of Husbandry.* (London: London: Printed for Richardson and Urquhart, 1776), p. 8.
[54] D. Young, *Agriculture, the Primary Interest of Great Britain* (D. Paterson, 1788), p. 200.

powder, which is of great service to their land."[55] The following year in the West Riding of Yorkshire, George Rennie similarly listed rape dust along with bones and horn shavings as the manures used. He wrote "…from the accounts we received, their effects are highly beneficial."[56] In 1795, John Aikin listed rape dust in *A description of the country from thirty to forty miles round Manchester* under the heading of "Manures" along with ground bones and horn shavings.[57] That same year Robert Somerville published numerous entries on rape dust in the *Outlines of the Fifteenth Chapter of the Proposed General Report of the Board of Agriculture on the Subject of Manures.* Farmers expressed support for an even greater expansion of the rape cake industry, and one claimed that rape dust for wheat doubled output.[58] "Communications from Sir Thomas, Bart. Respecting Rape Dust as a Manure" included entries on local use and pricing offered by multiple farmers. Mr. Clayton of Sherburn, indicated that rape cake tillage had been in use since the 1730s in his area. "[Rape manure] has been used these fifty or sixty years here very much; so if anything can be done by the Honorable Board of Agriculture, in lowering the price of rape dust, I will be very well; otherwise land in the country will certainly fall in its value (p 28?)," wrote Clayton.[59]

Based on the inclusion of rape cake and dust on lists of alternative manures, there is no question that the technology was used for improvement. As for the question of chronology, the

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[55] John Spurrier, *The practical farmer being a new and compendious system of husbandry, adapted to the different soils and climates of America : containing the mechanical, chemical and philosophical elements of agriculture : with many other useful and interesting subjects* (Wilmington Del.: Printed by Brynberg and Andrews, 1793), p. 181.
[56] G. Rennie, R. Broun, and J. Shirreff, *General View of the Agriculture of the West Riding of Yorkshire: with Observations on the Means of its Improvement*, ed. Board of Agriculture (Printed by W. Bulmer and Co., 1794), p. 26.
[57] Aikin, *A description of the country from thirty to forty miles round Manchester; ... The materials arranged, and the work composed by J. Aikin, M.D. Embellished and illustrated with seventy-three plates*, p. 95.
[58] Robert Somerville, *Outlines of the fifteenth chapter of the proposed general report from the Board of Agriculture on the subject of manures : drawn up for the consideration of the Board of Agriculture and Internal Improvement*, Goldsmiths'-Kress library of economic literature ;, (London: Printed by W. Bulmer, 1795), p. 39, 117.
[59] Somerville, *Outlines of the fifteenth chapter of the proposed general report from the Board of Agriculture on the subject of manures : drawn up for the consideration of the Board of Agriculture and Internal Improvement*, p. 117-21.

fact that these projects were conducted locally and distributed in early to mid-eighteenth-century magazines and newspapers as well as in improvement manuals generally suggests that rapeseed meal tillage was a valuable manure long before the 1815 period noted by Thompson. It was not until the end of the French Wars that England was importing about 1,000 tons of rape cakes per year and consuming an estimated 25,000 tons, claimed Thompson.[60] Bulk meal application peaked around this time as well. "Very slowly there developed an agricultural demand which conferred commercial value on these wastes when pressed and stamped into cakes," he wrote.[61] To the contrary, it is clear from these examples that rapeseed cake and dust left from the oil press were valued as a product and sold by mills as early as the 1720s, nearly 100 years before Thompson believed the plant manure revolution began. It is also clear from these primary sources that meal was composted directly into the soil through trial and error much earlier than 1815.

Like the revisionist models that trace the British Agricultural Revolution into the seventeenth or early eighteenth centuries, the evidence for early *B. napus* meal manuring explores a gradual evolution of the technology as it became better tested during the mid-and-late eighteenth century. While my methodology does not answer questions about the frequency of adoption or disbursal, such measures fail to gauge the importance of a technology that may have been used for specialized design goals such as to prepare poor soils for turnip foddering for convertible designs or to suppress soil molds and worms.[62] Instead, by establishing this chronology, we confirm that rapeseed cake, dust, and meal were used as a manure in the early modern agricultural sector. This soil amendment became gradually more integrated as a design

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[60] Thompson, "The Second Agricultural Revolution, 1815-1880," p. 67.
[61] Thompson, "The Second Agricultural Revolution, 1815-1880," p. 66.
[62] Due to the pandemic I was unable to finish ArcGIS models of seed mill disbursal to explore geographic disbursal. However this work is forthcoming.

element during the long eighteenth century, when after 1750 it was widely combined with other technologies and harnessed for a wide range of applications.

To take a second look at the chronology of rapeseed improvement and its economic implications, and also to explore potential environmental implications, the next section pieces together examples of *B. napus* manuring to control soil disease. While Thompson argues the cakes were more likely used for animal feed during this early phase, it is clear from period sources that farmers understood how rapeseed could be exploited to suppress pests. Rather than thinking of rapeseed as one of many recyclables to add to the earth to improve the general quality of the soil, eighteenth-century farmers also understood the amendment as a specialized environmental tool. The majority of historians continue to neglect *B. napus* and have no concept that it played a role in improvement, and many agronomists believe the technology is a modern invention. Yet taken as a whole, these localized eighteenth-century innovations represent an efficient and complex farming system of nutrient and energy recycling.

III. Rapeseed Manure for Soil Disease Suppression

Like most historians of the British Agricultural Revolution, Thompson, Chorley, and Overton wrote before the crop made a comeback in the modern agricultural sector, and before the mass digitization and indexing of historical manuscripts and rare books made possible the data mining and keyword searches critical to my own contributions. It is perhaps no surprise that they neglected the historical use of the technology to control molds and worms. Thompson is the biggest culprit as he focused an entire article on the economic importance of rapeseed and flax manures without considering the environmental mechanisms by which rapeseed manuring may have increased productivity. In keeping with the many authors who forwarded the nitrogen hypothesis as an explanation for late eighteenth-century advances in agriculture, Thompson generally believed that manures like bone meal played an important role. His findings on rapeseed meal were the product of more general studies of soil amendments and plant manures. Yet while Thompson suggested that crushed bones "supplied the phosphates and nitrogen required to enable these light lands to produce heavy crops of roots and grains," he did not attribute the same contributions to rape cake or dust.[63] As *B. napus* manure was used by period farmers to increase nitrogen and to fight soil worms and molds, this section explores *B. napus* meal and plantings as a pest deterrent or pest resistant option.

B. napus was studied by period farmers for its ability to target and prevent pest and mold problems. A clipping tucked inside Arthur Young's 1781 to 1818 correspondence at the British Library recommends rape cake for its resistance to mildew and ability to curtail the problems of rot. A typed note pasted into the diary reads:

> Rape-cake is an excellent manure for turnips, and does not subject them to mildew; they will grow longer than from any other manure; the turnip that grows most after Michaelmas is always of the best quality. Malt combs quick to bring the turnip to the hoe; rape-cake slow; where both are used they should be sown together.[64]

This same quote can be found published in the 1804 *View of the Agriculture of the County of Norfolk*, where Arthur Young attributes the comments to a local farmer named Mr. Johnson. [65] The work also references Mr. England of Binham, who "uses much rape-cake, and this year his turnips, thus manured, are his best."[66] However, the unpublished notes reveal a hand written comment that reads "the rape cake should be broken to the size of walnuts, and should be sown

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[63] Thompson, "The Second Agricultural Revolution, 1815-1880," p. 68.
[64] Note found between 102 and 103 in Volume 34853 XXXIII in. Arthur Young, *The Elements and Practice of Agriculture*, Unpublished, 1818, Add MS 34821-34854, British Library, Western Manuscripts.
[65] Arthur Young, *General View of the Agriculture of the County of Norfolk; With Observations on the Means of its Improvement* (Cambridge, MA, United States: Kress Library of Business and Economics, Harvard University, 1813), p. 419.
[66] Young, *General View of the Agriculture of the County of Norfolk; With Observations on the Means of its Improvement*, p. 420.

in April or May as near the second ploughing as conveniently can be done…"[67] While this example does not detail the use of *B. napus* to control pathogens, it suggests that period authors understood that rape-cake helped prevent mildew. *B. napus* increased the reliability of the turnip crop, which only flourished in poor soils the help of manuring.

In addition to serving as a mold-resistant manure, rape cake was also harnessed to fight pests. In 1817 John Sinclair published the first edition of the *Code of Agriculture*, which recommended crushed *B. napus* to treat European mole crickets--a species of insect pest that devour cereals and legumes as well as nursery plants. He wrote:

> It has been found in Flanders that powdered rape cake strewed over the surface of the ground destroys the *gryllus talpa* so injurious in wet soils and every insect of the same species may be destroyed by the same means.[68]

While Sinclair did not show that rape cake was similarly used as a pest treatment in England, he confirmed that it had long been used as a manure in Yorkshire and Norfolk. Rape cake was mixed in a five to one ratio with animal dung to manure turnips.[69]

Other examples highlighted wireworm suppression with *B. napus*. The example offered in the introduction is not the only reference to rapecake for pest control in the *The Farmer's Almanac and Calendar*. The July 1844 issue proposed the same solution:

> Rapecake powder has been successfully drilled with the turnip seed in Norfolk and Essex, at the rate of five or six cwt. per acre: this fertilizer is very noxious to the wireworm--the most stubborn of all the predatory vermin of the farmer's crops. Rape and coleseed may be sown this month, either after tares or among beans, to be fed off for wheat.[70]

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[67] Note found between 102 and 103 in Volume 34853 XXXIII.Young, The Elements and Practice of Agriculture, Unpublished.
[68] John Sinclair, *The code of agriculture, including observations on gardens, orchards, woods and plantations*, ed. Neely Sherwood, Jones, and John Sir Sinclair, Second edition. ed. (London: Printed for Sherwood, Neely, and Jones, Paternoster-row [and 4 others in 4 other places], 1819), p. 228-29.
[69] Sinclair, *The code of agriculture, including observations on gardens, orchards, woods and plantations*, p. 228-29.
[70] Cuthbert W. Johnson and William Shaw, "Farmer's Calendar-July," *The Farmer's Almanac and Calendar* v. 4 (1844). p. 29.

Other issues of the *Calendar* offered similar advice because the authors William Shaw and William Johnson Cuthbert widely circulated the recommendation.[71] Wireworms have often been found on land kept in sod or grass prior to conversion to crop, and as the pests are only millimeters wide and ½ inch long, but can be even smaller, they might only be identified when holes or tunnels are observed in tubers, plant roots, or seedlings.[72]

In an 1851 issue of *Working Farmer*, an article titled "On the Destruction of the Wireworm" advocated for rape cake above rape dust. Because the surface of the rape dust was thought too small and insignificant to fix the worms, the more sizeable clumps of manure offered by rape cake treatments were preferred. According to the article the recommended plan was as follows:

> In lieu of the ordinary top-dressing with rape-dust, apply to the land, and plow or harrow well in, five cwl. Per acre of rape-cake crushed into lumps about the size of half-inch ground bones, and the result will be that the wireworm will congregate on these lumps of cake, devouring them with such avidity as to become glutted and perish either from repletion or from the peculiar properties of the rape, or perhaps from the combined effects of the two.[73]

The method was thought so successful as to clear an entire property of wireworms within two years so long as all cultivated soils were treated. Here the detail of surface area and the size of the cake manure applications functioned as a design element that was modified based on trial and error.

In 1877 Eleanor Ormerod, lecturer at the Royal Agricultural College, began publishing annual surveys titled *Notes for Observations on Injurious Insects and Common Farm Pests.*[74]

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[71] Johnson and Shaw, "Farmer's Calendar-July," p. 29.

[72] Wireworms (Coleoptera: Elateridae) are the larvae of click beatles and devour crops at both life stages. Fanny Barsics, Eric Haubruge, and François Verheggen, "Wireworms' Management: An Overview of the Existing Methods, with Particular Regards to Agriotes Spp. (Coleoptera: Elateridae), *Insects*, 4, (2013), p. 117-18.

[73] "On the Destruction of the Wireworm," *Working Farmer* 3, no. 2 (04/1851), p. 38.

[74] E.A. Ormerod and R. Newstead, *Report of Observations of Injurious Insects and Common Farm Pests: During the Year 1877-1901, with Methods of Prevention and Remedy. [1st]-24th Report* (T.P. Newman, 1877).

She collected responses to a questionnaire distributed to farmers, professors, and other experts that she chose from personal contacts. From this work came an abundance of examples showing that *B. napus* manure crushed from the oil press had been widely used as a treatment for wireworm for decades and that similar practices had circulated as part of regional farming practices. While Ormerod's work may reflect a long history of the use of rape cake to treat wireworm and other pests, it is also important that she succeeded in co-founding the field of economic entomology by relating plant surveys to insect observations. [75]

Though Ormerod lacked the entomological classification system and microscopy power to distinguish species of wireworms, her findings are likely applicable across genera. Today researchers have identified more than 9,000 species of wireworm around the world.[76] While Brassica species have not been tested against each species, treatments have been moderately effective against several wireworms.[77] However before we emphasize the limits of Ormerod's period science, we must also acknowledge that her surveying project was hardly possible in the prior century. The foundational surveys conducted by the Board of Agricultural in the late eighteenth century were the first to make agricultural information exchange part of the landscape of improvement. Yet as they did not specifically ask farmers about pest treatments, the rare example is anecdotal. Through similar methods, Ormerod established the first survey evidence that rapecake manuring suppressed wireworm.

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[75] J. F. McDiarmid Clark, "Eleanor Ormerod (1828–1901) as an economic entomologist: 'pioneer of purity even more than of Paris Green,'" *The British Journal for the History of Science* 25, no. 4 (1992); ;Eleanor A. Ormerod, *Eleanor Ormerod, LL D., economic entomologist. Autobiography and correspondence*, ed. Robert Wallace (New York: E.P. Dutton, 1904).
[76] Fanny Barsics, Eric Haubruge, and François Verheggen, "Wireworms' Management: An Overview of the Existing Methods, with Particular Regards to Agriotes Spp. (Coleoptera: Elateridae), *Insects*, 4, (2013)," p. 117-18.
[77] Elberson et al., "Toxicity of rapeseed meal-amended soil to wireworms, Limonius californicus (Coleoptera: Elateridae)."

Ormerod included a survey question on the "serviceableness of various kinds of rape cake nuts or meal in diminishing the amount of injury from wireworm attack," though from the responses she collected it is clear that mechanisms were unknown. Similar to the discussion in *Working Farmer*, Ormerod even debated whether rapecake manure was a successful pest deterrent as it also draw wireworm away from plants by offering them a preferred food source. This very problem was suggested by Viscount Portman Bryanston Blandford, who believed rapecake attracted wireworms from the plant. "It may have killed them also, but of that I am not sure," he wrote to Ormerod.[78] Edward Gordon of Kelton Kirdcudbright agreed with this theory and described that the wireworm was very fond of rapecake and left the crop in order to feed on the manure. This freed the plant from attack.[79] Ormerod reports one study in which wireworms were placed on rapecake from the Black Sea, which was thought to be the highest quality.[80] In a second test group wireworms were placed on mustard cake. The latter seemed to be better, though the moisture in the two cake samples could not be controlled. Ormerod continued to debate whether wireworms feed so greedily on rape cake that they burst. [81]

Ormerod's correspondence included representatives from seed stores as much as gentlemen farmers and was compiled over the years prior to publication. George McQueen of the store Coed-y-Dinas in Welshpool wrote that in 1874 "I got two tons of very fine rape dust as fine as flour. I mixed it up with the turnip manure and sowed it in the drills in the usual manner.

[78] Ormerod and Newstead, *Report of Observations of Injurious Insects and Common Farm Pests: During the Year 1877-1901, with Methods of Prevention and Remedy. [1st]-24th Report*, p. 46.
[79] IBID.
[80] Ormerod and Newstead, *Report of Observations of Injurious Insects and Common Farm Pests: During the Year 1877-1901, with Methods of Prevention and Remedy. [1st]-24th Report*, p. 48.
[81] Ormerod and Newstead, *Report of Observations of Injurious Insects and Common Farm Pests: During the Year 1877-1901, with Methods of Prevention and Remedy. [1st]-24th Report*, p. 46.

The result was very good. There was no wireworm…" The next year McQueen used three tons "with the same good result."[82]

A farmer named R Paver Cron of Ornham Hall, Boroughbridge enclosed a piece of old pasture to convert it to a vegetable garden, but soon faced a wireworm invasion. The rape proved to work better than lime, salt, and soot, which were other recommended treatments for wireworm. "The first year the Cabbages were destroyed and large holes eaten in the potatoes by wireworm, and I dressed the garden thoroughly with lime salt and soot but notwithstanding the vegetables were destroyed," he writes.[83] The pest problem was just as bad the second year. "I then covered the garden with rape nuts and have had no wireworm since," writes Cron.

It is hard to find earlier examples that show the use of rapecake manuring to fight crop disease, but it is clear that prior generations of farmers similarly used *B. napus* plantings to target wireworm. Though additional examples of eighteenth-century rapecake manuring for pest control may be waiting to be found in the archives, it is the planted rape that was thought resistant to molds and used to control pests in the eighteenth century. More than a technological revolution, this points to a slow progression of farm design in which *B. napus* manuring became more commonplace during the same years that plantings of the species were tried for pest control. These two histories converged into a design framework that used manure for pest suppression.

The chronology of *B. napus* plantings for soil disease suppression begins more than a century before Ormerod. Already in the early eighteenth century, we find examples of planting strategies used to fight mold with rapeseed. In 1716 John Mortimer, a fellow of the Royal

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[82] IBID.
[83] Ormerod and Newstead, *Report of Observations of Injurious Insects and Common Farm Pests: During the Year 1877-1901, with Methods of Prevention and Remedy. [1st]-24th Report*, p. 47.

Society, published advice on the best way to fight soil mold in *The Whole Art of Husbandry: Or The Way of Managing and Improving of Land*. Mortimer recommended planting crops with rapeseed or madder, and then with corn. According to Mortimer:

> Rape and Cole-seed is another excellent piece of Husbandry and Improvement of Land, especially Marshy or Fenny Lands newly recovered from the Sea, or any rich rank fat Lands; the ranker they are the better: But they will do well on any Lands that are dry and warm. The best Seed is that which is biggest, fairest, and of a clear Colour like the best Onion-seed, and dry…[84]

From this focus on treating rank or rotting lands with rapeseed, we see that period farmers understood that rape was better suited to transform festering soils than many other crops. Also in 1716 John Worlidge wrote in *A Compleat System of Husbandry and Gardening:*

> The Planting and Propagating of Rape and Coleseed is esteemed another excellent piece of Husbandry and Improvement for Land, and more especially on Marh-Land, Fen-Land, or newly recovered Sea-Lands, or any Land rank and fat, whether Arable or Pasture.[85]

He advised finding the biggest and fairest coleseed. The best quality was of a clear color like onion seed and was usually from Holland. These examples suggest that rapeseed plantings made it possible to earn a profit from diseased lands that could support few other commodities and that the plant also helped turn moldy soils into cash-crop producing soils.

Later examples illustrate that farmers also used rapeseed plantings to directly cleanse the soil of disease. Charles Vancouver described in the 1794 *General View of the Agriculture in the County of Cambridge* that coleseed plantings were combined with pigeon dung and soot to fight pests like wireworm. He wrote "… whereon turnips and cole seed are sown; and sometimes soot upon wheat at spring, to embitter the surface and upper stratum of the land, to make the wire

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[84] John. Mortimer, *The Whole Art of Husbandry: Or, The Way of Managing and Improving of Land ... The Fifth Edition with New Additions* (George Grierson, 1721), p. 103.
[85] John Worlidge, *A Compleat System of Husbandry and Gardening: Or, the Gentleman's Companion, in the Business and Pleasures of a Country Life. ... The Whole Collected From, and Containing what is Most Valuable in All the Books Hitherto Written Upon this Subject* (J. Pickard, A. Bettesworth, and E. Curll, 1716), p. 74.

worms eating the wheat, retreat from it."[86] Vancouver's optimism about the success of this technology was based on accounts that entire crop fields would have been destroyed without preparing the land with a rapeseed planting. William Gooch confirmed that rapeseed was similarly used in Cambridge. "When the wire-worm is suspected, sow cole-seed two first years, which is an admirable practice…" he wrote.[87] Gooch believes that coleseed would destroy the insect more than any other tactic known. The combination of dung and spring soot is notable as a design element.

In another example, an essay published in the first years of the nineteenth century in *Communications to the Board of Agriculture* suggested that coleseed might help fight nematodes like the wireworm. According to Mr. Wing, the author:

> Some, when the wire-worm is suspected, sow coleseed the first years after breaking it up, which is an admirable practice, and tends more to the destruction of that noxious insect than any other that has come within the writer's knowledge: others lay their land down with coleseed the year after the second crop of corn, sowing their rye-grass and hay seeds with the cole, sheep-feeding it in the winter, and sowing the white clover the next spring, a method which is found to answer extremely well; and some with a crop of corn, which is esteemed the best mode for the seeds of any.[88]

It is remarkable that farmers like Mr. Wing noted the pest-killing benefits of coleseed without the use of modern scientific trials. While Wing did not use seed meal, he clearly understood the disease suppression benefits of *B. napus*.

Several references from the end of the eighteenth century suggest that rapeseed was sometimes planted after paring and burning to further reduce insect and pest problems. To pare the land, farmers used a breast-plough or turf-paring plough to clear a depth of two or three

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[86] Charles Vancouver, *General view of the Agriculture in the County of Cambridge: with Observations on the Means of its Improvement. Drawn up for the Consideration of the Board of Agriculture and Internal Improvement.*, ed. Board of Agriculture (London: Printed by W. Smith, 1794), p. 172.

[87] William Gooch, *General View of the Agriculture of the County of Cambridge*, ed. Agriculture Board of, Goldsmiths'-Kress library of economic literature ;, (London: Printed for Sherwood, Neely, and Jones, 1813), p. 104.

[88] John Wing, 'On the convertible System in the Management of Fen Lands, No. XXVIII,' *Communications to the Board of Agriculture*, 1804, pp. 497.

inches. After this dried, turf would be burned in heaps and the ashes distributed in the field. In 1811 in Huntingdon, Richard Parkinson recommended paring and burning before planting rape or cole in order to treat insect problems. Parkinson wrote:

> I have not given any manure in the whole time but such will please to observe that after the rape seed crop I have made a charge for burning the rape straw and stubble which is a second dressing after the paring and burning which I am of opinion would have the best effect for although paring and burning does destroy the eggs of flies which were laid there when in sward for their future progeny…[89]

In this example the flies are targeted before the pests have hatched through the destruction of their eggs. The land was pared and burned, the rape seed was planted, and the rape straw was then burned. This represents a highly sophisticated understanding of a mechanism of action for pest control, and it was implemented through a creative design that used two courses of fire and species-specific plantings in synch with insect life cycles. In 1808 Charles Vancouver similarly recommended sowing rape or cole on burnt ground in July at half a peck per acre.[90] Around this same time, John Farey wrote that in Derbyshire Mr. Geroge Clay of Arelston, grew two to four acres of rape annually on Sinfin Moor. He "sows half a peck of Seed at Midsummer, after pairing and burning," wrote Farey.[91] While these last two examples do not confirm a pest or pathogen suppression benefit, it is clear that *B. napus* was combined with paring and burning far beyond Huntingdon.

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[89] R. Parkinson, *General View of the Agriculture of the County of Huntingdon*, ed. Board of Agriculture (Phillips, 1811), p. 46.

[90] Charles Vancouver, *General view of the agriculture of the county of Devon; with observations on the means of its improvement: drawn up for the consideration of the Board of Agriculture, and internal improvement. By Charles Vancouver*, ed. Board of Agriculture (for Richard Phillips, Bridge Street; sold by Faulder & Son, Bond Street; J. Harding, St. James's Street; J. Asperne, Cornhill; Black, Parry, & Kingsbury, Leadenhall Street; E. Upham, G. Dyer, P. Hedgeland, & S. Woolmer, Exeter; Cobley & Company & Rees & Company Plymouth; & A. Constable & Company Edinburgh, 1808), p. 287.

[91] John Farey, *General View of the Agriculture and Minerals of Derbyshire: With Observations on the Means of Their Improvement*, ed. Board of Agriculture (B. McMillan, 1817), p. 140.

Rapeseed fallows also contributed the additional benefits of pest control. According to works like the 1820 *A Treatise on Mildew and the Cultivation of Wheat*, a fallow cycle of rape deprived the wireworms of food while exposing them to the elements. However "In cases where the land cannot have the advantage of an entire fallow, mangel wurzel or rape should be substituted for the turnip crop as those vegetables are less liable than turnips to be injured by the ravages of the wire worm," wrote Francis Blaike.[92] In this example, rape once again ensured crop success in situations where environmental constraint limited husbandry options. While the bare fallow was preferred, a planted fallow of rape was incorporated as a second option.

These examples illustrate the sophistication of localized improvement designs. Entire agronomic systems were structured and redesigned to mitigate and prevent pest problems. The timing of the burn as well as the ability to keep the heat steaming in the piles through several weeks without spreading fire to forests and fields was a technique that required gauging soil moisture, the chance of rain, the upwind or downwind location for the pile, and the depth of paring. If the rapeseed was sown too early after the ashes were spread, the soil would be too hot and potentially limit the germination process. If the seed was sown too late, it could not be followed by a crop and the profits of the cleansing would be lost. The chronological integration of coleseed with the paring, burning, and cropping was thus a more complex process than the mere use of just one of these technologies.

Keep in mind that as late as the 1770s growers like Arthur Young were still testing rapeseed in order to understand the best seasonal timing of planting and the number of ploughings and harrowings. In this way, the sophisticated designs described above tell us more about the evolution of the agronomical system than any introduction or disbursal history can

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[92] Blaikie, *A treatise on mildew, and the cultivation of wheat including hints on the application of lime, chalk, marl, clay, gypsum, &c. &c*, p. 16.

describe. Regardless of the first date of rapecake manuring for soil disease control in Britain, it is clear that by the late eighteenth century English and Scottish improvers began testing and comparing complex schematics that integrated rapeseed into a system of pest control. These examples point to a model of the British Agricultural Revolution described by the evolution of environmental design. *B. napus* earned a place in the literature of the British Agricultural Revolution because period farmers knowingly harnessed the technology to fight soil pests and molds as well as to improve poor soils for cash crops. While historical farmers did not consider the technology in chemical terms until the 1840s, and only modern growers have a working concept of the specific soil pathogens targeted by chemical components during the compost process, it is likely that Brassica meal manuring also offered a practical if imperfectly understood benefit of lessening soil disease in the eighteenth and nineteenth centuries. Not only did rapeseed make it possible to earn a profit from land that could support few other commodities, but it is likely the plant also helped cleanse wetlands of molds and pests so that higher value crops could be planted on converted soils.

IV. Rape Milling, Manuring, and Planting as a Cradle-to-Cradle Design

Research findings show that Brassica seed meals offer a level of crop protection comparable to that of conventional insecticide treatments, however treatments are most effective when soils are moist and at a suitable temperature of 10.5-16 °C, such as during the autumn or winter.[93] Wireworms are only killed if they are localized in the upper layers of the soil. Some proprietary blends of Brassica meals are though better at killing certain diseases, but the rate of

[93] Fanny Barsics, Eric Haubruge, and François Verheggen, "Wireworms' Management: An Overview of the Existing Methods, with Particular Regards to Agriotes Spp. (Coleoptera: Elateridae), *Insects*, 4, (2013), p. 130.

tillage determines the potency and rate of treatment.[94] The historical details of application may thus be more useful for modern farmers than chronology reconstructions. This section covers watering practices, oil concentrations, milling designs, and the rates of application in order to understand the increased rigor in agricultural design during the early and mid-nineteenth century when chemical analysis first became more widely published.

For example, eighteenth-century farmers clearly timed rapeseed manuring to synchronize with rainfall. According to Lord Hawke from the West Riding, it seems the rape meal had to be spread during a wet year in order to have the best impact. According to Hawke "…when we want rain in spring, and the weather is hot and dry, the manure is not of the least advantage, but loses its goodness from the heat of the weather and the want of rain."[95] Young wrote that in Norfolk, the rape cake is applied in April or May near the second ploughing in order to have a shower on it.[96] Mr. Johnson of Thurning intentionally sowed cake with turnip seed in a wet season. He wrote:

> If a dry summer follows a spring crop, dust does very little good; but if a rainy summer follows, I know of no better manure. For wheat, dust seldom misses; the two last wheat seed times, dust has been so scarce and bad to get**…**[97]

Similarly, returning to Somerville and his 1795 *Fifteenth Chapter of the Proposed General Report,* "For wheat, rape dust is considered a certain dressing, rain generally falling within a short time after sowing that grain."[98] One farmer that Somerville cited said "Should there come a very dry season immediately after the dust is laid on, I look upon it to be of no use as to the

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[94] Mark Mazzola, Shashika S. Hewavitharana, and Sarah L. Strauss, "Brassica Seed Meal Soil Amendments Transform the Rhizosphere Microbiome and Improve Apple Production Through Resistance to Pathogen Reinfestation," (2015).
[95] 105-6 in Volume 34853 XXXIII.Young, The Elements and Practice of Agriculture, Unpublished;
[96] Young, *General View of the Agriculture of the County of Norfolk; With Observations on the Means of its Improvement*, p. 420.
[97] Board of Agriculture, *Plan for reprinting the agricultural surveys* (1795), p. 28.
[98] Somerville, *Outlines of the fifteenth chapter of the proposed general report from the Board of Agriculture on the subject of manures : drawn up for the consideration of the Board of Agriculture and Internal Improvement*, p. 36-9.

increase of the crop sown along with it, the power of rape dust depending much upon the rain that falls in April and May."[99] Another farmer wrote:

> …if a dry season comes on after sowing, it does not answer the expectation; and I believe the last two dry summers of 1793 and 1794, those who were late in getting their spring crop set (the dry weather coming immediately on) used rape dust to very little or no purpose, which makes it at the present high price very discouraging to hazard so much in the spring crop; but if a tolerable wet season succeeds, it is sure to answer every expectation.[100]

Yet another described "If a dry summer follows a spring crop, dust does very little good; but if a rainy summer follows, I know of no better manure. G. H. Andrews wrote in *Modern Husbandry* that "[Rape cake and turnips] should never be sown when there is no prospect of rain following soon."[101]

Such examples are important because today the timing and amount of water application is thought to determine the release of glycosylates and isothiocyanate from the rapeseed cake or meal.[102] Such integrated designs ask farmers to work with the natural environmental patterns of seasonal rainfall, and many modern farmers work to achieve this same success in order to reduce irrigation and aquifer depletion. It is thus noteworthy that eighteenth-century farmers not only understood the seasonal planting calendar, but also realized that rapecake was only effective after it was exposed to the right amount of water.

In contrast, the standard for meal quality has much changed. Modern presses produce a dry, flaky meal and a coarse rapecake that lacks oil. The meal and cake are sometimes mixed with those of other Brassica species and pressed into a pellet for tillage. Eighteenth and early

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[99] Somerville, *Outlines of the fifteenth chapter of the proposed general report from the Board of Agriculture on the subject of manures : drawn up for the consideration of the Board of Agriculture and Internal Improvement*, p. 27.
[100] Somerville, *Outlines of the fifteenth chapter of the proposed general report from the Board of Agriculture on the subject of manures : drawn up for the consideration of the Board of Agriculture and Internal Improvement*, p. 27.
[101] G. H. Andrews, *Modern husbandry; a practical and scientific treatise on agriculture, illustrating the most approved practices in draining, cultivating, and manuring the land; breeding, rearing, and fattening stock; and the general management and economy of the farm* (London: N. Cook, 1853), p. 242.
[102] Ntalli and Caboni, "A review of isothiocyanates biofumigation activity on plant parasitic nematodes," p. 830.

nineteenth-century farmers had the opposite goal; they worked to increase the oil content of rapecake and the fine consistency of rape powder. This is because rich, fatty soils with more oil were thought to create the fertility needed for the next year's crop. Plants were also evaluated as oily or dry in order to predict their potential to exhaust the earth while growing. If a plant's haulm or stock were too woody, it was thought exhausting. This is because plants with woody stems or stem fragments took too long to decompose and broke down into larger rather than smaller bits. Oils refurbished the soil, and like flax and malt, rapeseed returned fat lost to crop production back to the earth. Many farmers even took to milling their own rape for manuring to control the oil and consistency of the cake and dust. They then carefully tested rates of application per acre and documented these findings.

In 1795 Robert Somerville wrote in the *Outlines of the Fifteenth Chapter of the Proposed General Report from the Board of Agriculture on the Subject of Manures* that rapecakes were used as manure both upon fallows for wheat, barley, and turnip crops. "The ordinary way of preparing [rape cake] is by breaking it with a mill, and sowing it by hand before the fallows receive the last ploughing," wrote Somerville. However Somerville was most interested in the oil concentration and final manure preparation. He continued "...it is worthy of notice that as the valuable principle on this Manure consists of oil only, and that in a hardened state, it is much improved by being mixed with active substances, such as lime or alkaline salts, in order to make it act properly."[103]

In 1813 Thomas Batchelor of Bedford described the ameliorating properties of rapeseed, which boasted the richest of all manures. "If any plant be suffered to ripen its seeds, it loses nearly all its ameliorating properties, but of this the oil-bearing kinds furnish the most

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[103] Somerville, *Outlines of the fifteenth chapter of the proposed general report from the Board of Agriculture on the subject of manures : drawn up for the consideration of the Board of Agriculture and Internal Improvement*, p. 39.

indisputable proofs," he wrote.[104] Bachelor similarly emphasized that the oil itself was considered the richest of all manures. He advised that "…seven or eight hundred weight of rape cake is considered sufficient to manure an acre of land…" and went on to describe how seeding for rape had the additional benefit of producing abundant flowers for the bees and expanding hive size.[105] Also in 1813, Charles Vancouver listed rape and malt dust on a list of manures and wrote that by decomposition they "yield a mucilage which contributes essentially to the nourishment of plants."[106] Included on the same list were refuse fish and blubber, pond and river mud, farm and stable dung, and woolen rags for "containing a large proportion of fermentable animal mucilage given out by putrefaction, about 6 cwt."[107] This fascination with oil and fat to regenerate and improve the soil persisted through the mid-nineteenth century. In *Modern Husbandry,* G. H. Andrews wrote that rape cake was a desirable manure containing "…albumen, mucilage, and some oil," he continues "it is used as a top dressing chiefly, but may be applied in any other manner."[108]

Understandings of the refurbishing properties of rapecakes motivated farmers to test the best milling techniques to achieve the right fat content. A note in Arthur Young's 1781 and 1815 correspondence at the British Library shows that in the West Riding of Yorkshire, Lord Hawke built his own mill to grind rape-cake so that the oil-rich dust might not be mixed. Hawke complained that rape cake was not of the best advantage to the soil in the hot, dry weather, and

[104] Thomas Batchelor, *General View of the Agriculture of the County of Bedford: Drawn Up for the Consideration of the Board of Agriculture and Internal Improvement* (Sherwood, Neely and Jones, 1813), p. 424.
[105] Batchelor, *General View of the Agriculture of the County of Bedford: Drawn Up for the Consideration of the Board of Agriculture and Internal Improvement*, p. 579.
[106] Charles Vancouver, *General View of the Agriculture of Hampshire: Including the Isle of Wight* (London: Printed for Sherwood, Neely and Jones, 1813), p. 462.
[107] Vancouver, *General View of the Agriculture of Hampshire: Including the Isle of Wight*, p. 461.
[108] Andrews, *Modern husbandry; a practical and scientific treatise on agriculture, illustrating the most approved practices in draining, cultivating, and manuring the land; breeding, rearing, and fattening stock; and the general management and economy of the farm*, p. 242.

opted to invest in a mill to afford the opportunity to manure with rapecakes during the rainy spring season. While he formerly paid as much as 300 pounds for rapecakes within eight months, his mill and granary cost only 160 pounds to build. This provided the additional benefit of a more oil rich manure. “The cake now is not so good as formerly, for the manufacturers of rape oil now contrive to press their cake twice, whereas formerly they never pressed it more than once; and they used horses where they now use water, wind, and steam,” Hawke complained.[109] His account was published in 1804 in the *General View of the Agriculture of Hertfordshire*, and shows that the size and oil content of rapeseed manure was modified to increase beneficial properties.[110]

In 1795 Alexander Hunter expressed a similar concern in *Outlines of Agriculture Addressed to Sir John Sinclair*. He wrote that “at present, that useful article of husbandry is much diminished in goodness, owing to the improved methods of extracting the oil from the rape. Heat and pressure are employed in a double degree, and every other method is used to the prejudice of the farmer.”[111] Despite this, rapeseed-dust sold for as much as 19 shillings per quarter, causing Hunter to declare the technology “a speedy and certain manure, though an expensive one.”[112] As to the definition of a quarter, Hawke wrote “Six quarters and two bushels make a ton, but with many dust-sellers, as it is said, seven.”[113] Hawke purchased ten tons for 51

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[109] 105-6 in Volume 34853 XXXIII.Young, The Elements and Practice of Agriculture, Unpublished;

[110] Arthur Young, *General View of the Agriculture of Hertfordshire: Drawn Up for the Consideration of the Board of Agriculture and Internal Improvement* (G. and W. Nicol, 1804), p. 169-70.

[111] Alexander Hunter and John Sinclair, *Outlines of agriculture addressed to Sir John Sinclair* (York: York: Printed by Wilson, Spence and Mawman, 1795), p. 10.

[112] Hunter and Sinclair, *Outlines of agriculture addressed to Sir John Sinclair*, p. 10.

[113] Young, *General View of the Agriculture of Hertfordshire: Drawn Up for the Consideration of the Board of Agriculture and Internal Improvement*, p. 169-70.

pounds, 173 shillings and six pence. Bradley wrote that rape cakes sold for three pounds and ten shillings per thousand pounds in weight.[114]

Thompson related the price history of rapecake to its uses for agricultural improvement, and my analysis emphasizes the significance of a local milling economy to agronomical design. Thompson showed that the relative prices of rapeseed oil and cake increased over the eighteenth century and into the nineteenth century, thus illustrating increased demand. "Linseed oil and rape oil were equally valuable, and each sold at virtually the same price per gallon both in the 1760s and in 1816; but whereas linseed cake was worth only 1/36 times as much as rape cake in the 1760's, in 1816 it was worth over three times as much," wrote Thompson. "Though rape subsequently became a little more popular, the ratio settled down through most of the nineteenth century at 2:1 in favor of linseed."[115] This suggests that rape may have initially been used as a manure because it was cheaper than linseed cake, but as the technology caught on and proved more effective, rapecake became disproportionately expensive. In fact, Thompson argued that through the course of the plant manure revolution, the price of rapecake and oil became co-determinant. When both products became commodity items, cake markets began to influence oil prices. Yet Thompson did not go so far as to independently track either commodity over time or relate demand for oil crushing to fluctuations in textile markets. Such a highly schematic price inflation model is less helpful in an economy full of backyard producers and small-scale, self-sufficient farms that established their own mills to ensure quality. It is clear from primary historical sources that farmers exercised this level of engagement in rape dust milling. For

[114] Bradley, *A complete body of husbandry; collected from the practice and experience of the most considerable farmers in Britain. ... Adorn'd with cuts. By R. Bradley*, p. 95.
[115] Thompson, "The Second Agricultural Revolution, 1815-1880," p. 66.

example, in addition to controlling the oil content, farmers also worked to modify the size of the powder.

In the *General View of the Agriculture of the County of Norfolk*, Young relayed rapeseed milling instructions from the local farmers. He wrote that in Norfolk "rape cake should be broken to the size of walnuts less the dust should be better sown."[116] The dust was clearly of a smaller size than the original cake, and this was the product of local modification. In the *General View* for Hertfordshire Young similarly detailed that "Rape-cake in dust is used at the Hadhams, at 20 s. a quarter… There are mills that grind it at Ware."[117] This suggests that the rape cake was either mixed with smaller components or further ground. However Young also offered numerous examples of local modification conducted onsite by village farmers. For example, Mr. Greg of Hertfordshire imported large quantities of rape-cake from Ireland and then ground the product on site. Young wrote that Mr. Greg "…has attached to his thrashing-mill a stone for grinding it to dust, as a manure, the use of which he much approves."[118] This confirms that some farmers purchased the rape cake as a bulk material for manuring while others used a home-constructed mill to grind the manure into a smaller form.

Examples like these confirm that *B. napus* was locally milled and applied. Even if rapeseed was not locally grown in every region, the integrated nature of the local milling design allowed some farmers to continue innovation despite price spikes, which seem to be more tightly correlated with oil rather than seed prices. Though dust may have suffered price increases, it is

[116] Young, *General View of the Agriculture of the County of Norfolk; With Observations on the Means of its Improvement*, p. 420-22.
[117] Young, *General View of the Agriculture of Hertfordshire: Drawn Up for the Consideration of the Board of Agriculture and Internal Improvement*, p. 162.
[118] Young, *General View of the Agriculture of Hertfordshire: Drawn Up for the Consideration of the Board of Agriculture and Internal Improvement*, p. 168.

clear that local milling design innovation was also driven by the desire to control performance variables.

Today, rapecake produced from the first milling contains fat and some oil, and it is often given to animals as feed for the rich omega-3 acids. It has the consistency of soft potting soil and the color is dark brown. The meal left from the second pass through the mill is more powder-like and has greater fiber content. It is lighter in color, flaky, and could perhaps be described as "dust" due to the lower oil concentration.[119]

Eighteenth century milling technology produced a product of a slightly different composition and may have contained more oil. Nathaniel Kent suggests that in Norfolk a robust localized milling infrastructure had already been established to modify the size of the cake by 1813. We gain a more vivid image of the milling technology even if not the final size of the dust from Kent's description:

> Some persons use rape-cake for turnip manure; and Mr. Styleman, of Snettisham, a gentleman of considerable fortune, who farms part of his estate upon a large scale, and is trying many ingenious experiments, uses it in a pulverized state, to which he reduced it by means of two mills, worked by two women, each mill being formed of two cylinders revolving towards each other. The first breaks the cake into pieces of the size of a walnut by the operation of cogged cylinders; the second is constructed of plain cast iron cylinders similar to those used for grinding clay to make bricks.[120]

The second mill reduced the cake for powder so that it could fit into the seed drills used to distribute turnip or wheat seed. "The quantity of cake is a quarter of a ton per acre," wrote Kent.[121] Interestingly, Kent's account may have been based on an 1804 article published by

[119] Cohen and Mazzola, "A reason to be optimistic about biodiesel: seed meal as a valuable soil amendment;" D.S. Kimber and D.I. McGregor, *Brassica oilseeds: production and utilization* (CAB International, 1995); Potgieter, De Beer, and Claassens, "The effect of canola (Brassica napus) as a biofumigant on soil microbial communities and plant vitality: a pot study."
[120] Nathaniel Kent, *General View of the Agriculture of the County of Norfolk; with Observations for the Means of its Improvement* (London: R. Phillips, 1796), p. 41.
[121] Kent, *General View of the Agriculture of the County of Norfolk; with Observations for the Means of its Improvement*, p. 40-3.

Chorographus in *Agricultural Magazine*. In his article "On the Agriculture of the County of Norfolk," Chorographus also described a Mr. Styleman of Snettisham who employed women with hand-mills to reduce rape-cake to powder. He spread the pulverized manure into recently planted seed beds.[122]

Rates of seeding and application were not documented by accident. Density of seed disbursal and the rate of manuring in gallons or tons per acre were often the first things that farmers tested. As early as 1727, Bradley documents that one thousand cakes provided enough manure for three acres, and each cake weighed about two and a half to three pounds.[123] Jumping to the end of the century, in 1795 Somerville quoted a local farmer as having used "Upon an average three quarters and one sack of rape dust for barley, and two quarters and one sack for wheat. The average price for the three last seasons is 19s per quarter."[124] Another farmer offers similar estimates in the same section. "The usual and necessary quantity of Rape Dust for the spring crop is three quarters per acre… the increase of the crop in general I believe, to be nearly half (in a following season such as the present one is)."[125] A farmer named Mr. Hodgson confirms that "…people lay upon an acre for wheat three quarters; others lay upon an acre two quarters; but upon an average I suppose two quarters and a half."[126]

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[122] Chorographus, "On The Agriculture of the County of Norfolk," *Agricultural Magazine* v. 10, no. 55 (1804). p. 97.
[123] Bradley, *A complete body of husbandry; collected from the practice and experience of the most considerable farmers in Britain. ... Adorn'd with cuts. By R. Bradley*, p. 95.
[124] Somerville, *Outlines of the fifteenth chapter of the proposed general report from the Board of Agriculture on the subject of manures : drawn up for the consideration of the Board of Agriculture and Internal Improvement*, p. 118.
[125] Somerville, *Outlines of the fifteenth chapter of the proposed general report from the Board of Agriculture on the subject of manures : drawn up for the consideration of the Board of Agriculture and Internal Improvement*, p. 118-20.
[126] Somerville, *Outlines of the fifteenth chapter of the proposed general report from the Board of Agriculture on the subject of manures : drawn up for the consideration of the Board of Agriculture and Internal Improvement*, p. 118-20.

Rapeseed meal manuring for soil improvement was so well integrated into the agricultural system that farmers published rates for cake and dust. Period farmers also paid attention to soil types when describing the best rates of meal disbursal. In 1804, Young wrote that in Hertfordshire rape-dust was laid at a rate of three quarters or near half a ton per acre from Cambridge to Barkway.[127] In another passage he noted that rape-cake was laid as 12 to 24 bushels per acre, depending on the "goodness of the land."[128] In another note he documented that pulverized rape cake was applied at a rate of 6 to 20 bushels an acre, though it is not clear if he is mixing the cake with yard mulch.[129] In Norfolk Young observed that rapecake was spread at a rate of ¼ of a ton per acre and the land was then used to grow fodder to feed sheep for manure.[130] In 1809 William Pitt documented that in Northampton rape or coleseed was sown before Midsummer at the rate of a gallon per acre.[131] In Hampshire, Vancouver observed that rape was sown around the first of July at a rate of 6 pounds per acre with three bushels of ray grass for spring food.[132] This prepared the rape for the first feeding by the beginning of October, and the ray grass would follow later to keep the pasture under continuous grazing.[133]

Because rapeseed could be applied to the soil in many different ways, it was also frequently combined with other manures and marles. In 1794, Isaac Leatham wrote "A great quantity of soot and pigeons' dung is also used with some rape dust but the price of the latter is become so very high that less is now used than formerly." He continues by saying "These are

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[127] Young, *General View of the Agriculture of Hertfordshire: Drawn Up for the Consideration of the Board of Agriculture and Internal Improvement*, p. 169-70.
[128] Young, *General View of the Agriculture of Hertfordshire: Drawn Up for the Consideration of the Board of Agriculture and Internal Improvement*, p. 169-70.
[129] Young, *General View of the Agriculture of Hertfordshire: Drawn Up for the Consideration of the Board of Agriculture and Internal Improvement*, p. 105.
[130] Young, *General View of the Agriculture of the County of Norfolk; With Observations on the Means of its Improvement*, p. 203.
[131] William Pitt, *General View of the Agriculture of the County of Northampton* (R. Phillips, 1809), p. 99.
[132] Vancouver, *General View of the Agriculture of Hampshire: Including the Isle of Wight*, p. 214.
[133] Vancouver, *General View of the Agriculture of Hampshire: Including the Isle of Wight*, p. 214.

generally spread upon the surface by hand. It would be more beneficial to incorporate them with earth…"[134] Returning to Alexander Hunter, rape manure was generally considered to be a top dressing much like soot, malt dust, and pigeon dung in that it was cast over the earth rather than worked into the land by plough.[135] While these details may seem mundane, they are a glimpse into the design elements that afforded farmers the ability to manage private lands by adapting best practices to their unique soils.

By the mid-nineteenth century, these design questions became more rigorously and quantitatively tested. In 1842 as the English translation of Liebig's work was raising concerns of nitrogen depletion in a new readership, an article titled the "Relative Value of Different Manures" appeared in *The Farmer's Monthly Visitor* to compare the amounts of manures like woolen rags, cow hair, animal bones, soot, and saw dust needed to substitute the same amount of nitrogen found in 1000 pounds of farm yard manure.[136] Rape cake placed in the middle of the rankings of nitrogen composition by manure type. Only about 81 pounds of rape cake were thought needed to deposit the same amount of nitrogen available in 1000 pounds of farm yard manure. In contrast, sawdust from oak required 740 pounds though 2,119 pounds from fir were needed to accomplish the same goals. According to the article, manures like rapeseed "are the foundation of the farmer's prosperity. He can do nothing without—he can do everything with them."[137] Hence the detailed breakdown of the relative nitrogen contributions offered by the co-products of industry and farm management. If using soot from coal, farmers needed to apply 296 pounds, and if soot from wood, 347 pounds to offer the same nitrogen found in 1,000 pounds of

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[134] Isaac Leatham, *General View of the Agriculture of the East Riding of Yorkshire, and the Ainsty of the City of York : with Observations on the Means of its Improvement*, ed. Board of Agriculture (London: Printed by W. Bulmer and Co., 1794), p. 53.
[135] Hunter and Sinclair, *Outlines of agriculture addressed to Sir John Sinclair*, p. 13.
[136] "Relative Value of the Different Manures," *Farmer's Monthly Visitor* 11, no. 12 (05/31/1842), p. 71; W. H. Brock, *Justus von Liebig : the chemical gatekeeper* (Cambridge ; New York: Cambridge University Press, 1997).
[137] "Relative Value of the Different Manures," p. 71.

farm yard manure. Interestingly, only 22 pounds of woolen rags, 29 pounds of cow hair, or 57 pounds of animal bones were needed because these amendments were thought so concentrated.[138] Even if we limit our understanding of manuring improvement mechanisms to nitrogen fertilization, as some period sources do, it is clear that *B. napus* is included on the same list as the more popular tools used for this purpose.

While these estimates may or may not be accurate by modern standards, they confirm the importance of rates of application per acre to period farmers and highlight the incorporation of resources now considered waste products. As to why this chapter omits study of woolen rags, flax meal, cow hair, or the other alternative manures, it is *B. napus* that continued to develop into an engineering solution. In 1853 G. H. Andrews evaluated a technical solution to the problem of manuring for his readership. At Myer Mill-Farm near Maypole in Ayrshire, guano and superphosphate of lime were mixed with well water through the use of a hydraulic pump. "A certain amount of fermentation [was] induced by the addition of rape-dust…," wrote Andrews.[139] The water was delivered at a rate of 4,000 gallons an hour to an acre.   These details reflect precision cake manuring that evolved from studies of cultivation parameters. This level of structure was made possible by a long course of trial and error that spanned many generations. Andrews shows that farmers both combined rapeseed cake with other ingredients and used their recipes to spur a reaction for distribution to the fields at a rate-monitored flow.

This versatility of *B. napus* as both a design element and an engineering solution complicates Thompson's geotemporal model of the British Agricultural Revolution, which compares early regional mechanization in some areas to the later but more rapid adoption of new

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[138] "Relative Value of the Different Manures," p. 71.

[139] Andrews, *Modern husbandry; a practical and scientific treatise on agriculture, illustrating the most approved practices in draining, cultivating, and manuring the land; breeding, rearing, and fattening stock; and the general management and economy of the farm*, p. 228.

technologies in other locations. Thompson argues that Wales waited until 1939 to revolutionize, and its transformation was characterized by a rapid advance from early modern practices to the tractor.[140] In most other areas the first wave of innovation concluded with Parliamentary enclosure at the end of the eighteenth century. Thompson writes:

> Before 1815, the embryo of the second revolution was present, but it only developed markedly thereafter; by about 1880 the force of this revolution was spent, its hallmarks were widely spread over the farms of the country, and any further spread was checked by the great price fall.[141]

In addition to the widespread adoption of mechanized technologies, this first wave of revolution was characterized by technical changes in crop rotations and livestock improvement combined with intensified closed system farming.

Yet my research shows that rapeseed dust and cake were used in manure recipes that changed very little in terms of complexity between the early seventeenth and late eighteenth centuries. *B. napus* manuring appeared in many regions of England and matured along with regional designs. Not only did manuring innovation began at least fifty to 100 years earlier than Thompson indicated, but the diversity of *B. napus* designs over the long nineteenth century points to a slow evolution of a more robust agronomic system. [142] Designs gradually became implemented with greater precision and more site-specific diversity. By using *B. napus* as an indicator of design evolution, agricultural change appears to have been slower and less progressive though ultimately cumulative across most regions.

Despite this longer-term evolution of design, the late eighteenth century still stands as a time of agricultural development even if for the over-all strength and robust nature of design.

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[140] Thompson, "The Second Agricultural Revolution, 1815-1880," p. 65-6.
[141] Thompson, "The Second Agricultural Revolution, 1815-1880," p. 65-66.
[142] Thompson, "The Second Agricultural Revolution, 1815-1880," p. 66.

In *The Agricultural Revolution*, Kerridge was unabashedly forward when he wrote "This book argues that the agricultural revolution took place in England in the sixteenth and seventeenth centuries and not in the eighteenth and nineteenth."[143] He quickly dismissed Lord Ernle's mid-eighteenth century chronology of fodder and grass revolution as unsupported by a single shred of evidence and asserted a much earlier transformation that occurred a century prior.[144] Yet while B. *napus* was introduced and tested long before the classic 1760-1880 phase of agricultural revolution, the more intricate and precise design innovation distinguishes the later eighteenth century from the innovations of the prior century. It is the long eighteenth century when designs incorporate application rate structures, milling design descriptions, and timed waterings.

These details reframe the debate over the nitrogen thesis. The story of *B. napus* meal tillage may at first seem to forward the goals of historians like Chorley, who referenced the increased nitrogen availability made possible by plant manures when he described increased nutrient recovery by legumes as a late eighteenth and early nineteenth-century innovation.[145] Yet Chorley stops short of developing a model that integrates manures like rapeseed into the nitrogen cycle. When he mentions manures at all, they are but a citation in a footnote mentioned as part of a long list of fodders and animal rotations thought to increase nitrogen. Nor does Chorley consider mechanisms by which plant manures may or may not improve soil structures to better nutrient retention and availability. Mark Overton similarly makes little mention of *B. napus* and only notes the importance of new manures in increasing soil nitrogen. "In fact, it is possible to identify many strategies adopted by farmers which would have made more nitrogen available to

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[143] Eric Kerridge, *The Agricultural Revolution* (New York: A.M. Kelley, 1968), p. 15.
[144] Eric Kerridge, "The Agricultural Revolution Reconsidered," *Agricultural History* 43, no. 4 (Fall1969 1969). p. 467.
[145] Chorley, "The Agricultural Revolution in Northern Europe, 1750-1880: Nitrogen, Legumes, and Crop Productivity," p. 78; Chorley, "The Agricultural Revolution in Northern Europe, 1750-1880: Nitrogen, Legumes, and Crop Productivity."

cereals…. Better use was made of existing manures, and, from the mid-seventeenth century, greater use of new manures was advocated…" writes Overton.[146] Yet he does not attempt to compile lists of alternative manures used nor does he piece together a study of the period uses and understandings of any given manure. Such cursory references to plant and other non-animal manures in the British Agricultural Revolution fail to uncover period design details.

As the current case study of *B. napus* illustrates, we cannot reduce the environmental mechanisms of plant manures to increased nitrogen fixation. The importance of nitrogen fixing fodders to Chorley's model must now be reframed to consider the many period sources that confirm use of *B. napus* to target worms and other soil pests. The stimulation of the growth of beneficial microbes by *B. napus* reflects its potential to improve the overall health of soil, which in turn increases the bioavailability of nutrients. Though Overton suggests that plant manures primarily served to increase nutrients in the eighteenth-century landscape, we see that *B. napus* altered the very microbiome. Such a transformation impacts every aspect of plant-soil exchanges. Tello also described how fodders for feed primarily increased animal manure, and thus set in place a cascade of changes in the soil by altering the temperature of the earth where nitrogen fixing bacteria performed. Yet *B. napus* outlines an entirely new role for human-caused changes to soil organisms as the ratios and populations of key pests and pest fighters were changed.

Even if deposition from manuring merely recycles nitrogen, the potential to amend the soil serves many benefits. Here we depart from the chemical concepts of fertilization and manuring introduced by Liebig, who believed that nutrients must be added to the soil after cultivation to replenish levels. "He was, therefore, the founder of the artificial fertilizer

[146] Mark Overton, "Re-Establishing the English Agricultural Revolution," *The Agricultural History Review* 44, no. 1 (1996), p. 11.

industry," wrote James Galloway in his paper *A Chronology of Human Understanding of the Nitrogen Cycle*.[147] Though Liebig incorrectly believed that nitrogen primarily entered the farm through rain and dew, his work inspired John Bennet Laws and Joseph Henry Gilbert to treat fields in Rothamsted with ammonium sulfate. As early as 1843 Laws and Gilbert showed that chemical fertilizer dramatically increased crop yields. Thus, in the mechanistic model attributed to Liebig and his colleagues, fertilizer is external to the farm system. Today agricultural design continues to externalize both inputs and waste. Synthetic fertilizer is brought to the field across many hundreds if not thousands of miles after mining and processing. Nitrates then leach into surface waters, where they concentrate in rivers, lakes, and ocean basins, and potentially contribute to eutrophic and hypoxic water conditions. For example, in the Gulf of Mexico, the "dead zone" caused by nitrate pollution continues to threaten the commercial fishing and shrimping industries. Pollution comes from fertilizers applied as far away as Illinois and Wisconsin, where agricultural waste drains into the Mississippi River.[148]

In contrast, the environmental impacts of *B. napus* are at best and worst slow and cumulative in the soil over time. Perhaps the strongest case for its late eighteenth-century environmental impact is the introduction history that dates manuring to the earlier part of the same century. Designs were tested early enough so as to allow for a gradual integration of technology into the many designs featured in this work. In these designs *B. napus* was rarely if every repeatedly applied to soils. Yet over the decades it is likely that sites were treated more than once. In contrast to chemical treatments, *B. napus* was also integrated into every stage of local milling and site-specific designs. We know that in-house mills were constructed by farmers who sought more control over the oil concentration of *B. napus* manures. Application

[147] James et al., "A chronology of human understanding of the nitrogen cycle," p. 4.
[148] "The Gulf of Mexico Dead Zone," accessed May 18, 2020.

rates varied by site and were thus tested by the tenant farmer or landlord. Finally, farmers sometimes grew their own seed to produce manure, thus placing the entire production cycle on site. The grazing of *B. napus* oilseed for milling and manuring further illustrates the local nature of period designs, as does the diversification of application practices by soil type. Yet *B. napus* was more than a locally grown manure; it was also a versatile design element that allowed every waste to serve as an input. In conclusion, even though eighteenth and nineteenth-century farmers may not have understood the mechanisms by which manures helped fight pests and increased the cycling of nitrogen, they fostered a unique cradle-to-cradle design that altered the very soils of rural England and Scotland. Though the many local examples in this study do not necessarily add up to a national trend, it remains problematic to conclusively construct this big picture analysis for even the better studied crops like clover and turnips. In a genera that relies heavily upon localized case studies, it is clear that *B. napus* meal tillage played a larger role in agricultural development than was previously thought.

CONCLUSION

Historians who attempt to define the British Agricultural Revolution open a can of worms. Worse yet, the complexities of the chronology of improvement introduce ambiguities to any debate that links agricultural development to the British Industrial Revolution. What then can we say about the grand importance of a mere alternative crop like *B. napus*, which was likely planted at an even smaller scale than the crops that traditionally but contentiously signal progress? This final section emphasizes the need for additional research in order to aggregate local examples of *B. napus* dispersal and design innovation into regional and national improvement trends. The problem of cereal and meat import histories during the period is also discussed in the context of the narrative of agricultural progressivity.

I begin by borrowing from Joel Mokyr's analysis of the British Industrial Revolution imaginary because a similar critique can be made of our attempts to rewrite the agricultural past. The phrase "British Industrial Revolution" was widely used by 1948 and generally described economic and technological advances that occurred between 1760 and 1830.[1] However nearly every aspect of this model can be pushed backwards or forwards by as much as 100 years depending on whether modern historians focus their studies of the British Industrial Revolution on macroeconomic change, social transformation, the emergence of new financial and industrial sectors, changes in the seasonal timing of marriage as a signifier of laborers employed in industry rather than planting, or the development of certain technologies which may have been

[1] Cannadine David, "The Present and the Past in the English Industrial Revolution 1880-1980," *Past & Present*, no. 103 (1984); Joel Mokyr, "The Industrial Revolution and the New Economic History," in *The Economics of the Industrial Revolution*, ed. Joel Mokyr (Totowa, NJ: Rowman & Allanheld, 1985).

less progressively adopted and cycled through boom and bust markets.[2] "The important point to keep in mind is, of course, that from a purely ontological point of view, the British Industrial Revolution did not "happen," wrote Joel Mokyr in his editors introduction to *The Economics of the Industrial Revolution.* "What took place was a series of events, in a certain span of time, in known localities, which subsequent historians found convenient to bless with a name."[3] The rate of economic and technological change is also widely debated. Some contemporaries spoke in terms of "wonderful progress of manufactures," but others did not notice any change at all.[4]

A similar question can be asked about the relationship between agricultural and economic development: Was there an Agricultural Revolution, and if so when did it happen? Period actors spoke in terms of agricultural improvement rather than revolution. As this dissertation has discussed at length, even crops introduced in the early seventeenth century may have been poorly integrated until convertible husbandry and rotations of fodder, livestock, and cash crop became more widely integrated into a robust system of agronomic design. This begs larger questions of the chronology of enclosure and the emergence of larger farm sizes. Similarly, in tracing new crops like turnips, clover, Lucerne, and Sainfoin from their introduction to field husbandry in the early-to-mid seventeenth century, we must note that innovation spanned at least a century-and-a-half before fossil inputs such as synthetic fertilizers entered fields in the mid nineteenth century. Somewhere along the way complex rotations were implemented and mechanized technology became more widely adopted for this purpose. Yet historians continue to debate the impacts of mechanical and plant innovations thought to drive changes in soil fecundity and productivity.

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[2] Mokyr, "The Industrial Revolution and the New Economic History," p. 4-8; Emma Griffin, *A Short History of the British Industrial Revolution* (Houndmills, Basingstoke, Hampshire; New York: Palgrave Macmillan, 2010), p. 75-8.
[3] Mokyr, "The Industrial Revolution and the New Economic History," p. 1.
[4] Mokyr, "The Industrial Revolution and the New Economic History," p. 4.

Not only are introduction histories contentious, but it is difficult to show widespread planting over large spans of acreage on the average farm, much less with a high frequency of adoption over regional geographies. This confounds attempts to correlate innovation with increased yields.

This dissertation addresses an even more concerning problem. The question of the complete farm design as it evolved through the early modern period to the nineteenth century has often set aside for research on clover dispersal, the chronologies of course rotation, Tullian seed drilling and horse-hoeing, convertible husbandry and enclosure, or the introduction of field turnips. There are few scholars who attempt to integrate these many pieces of the puzzle into a comprehensive history of temporal and spatial design evolution due to the demands of a rigorous study of any single part of the whole. Because the details of technology combinations exceed the scope of the typical study and are often dismissed as minutia, we can say very little about what actually worked and did not work.

By putting an alternative crop like *Brassica napus* (*B. napus*) in the spotlight, I do not mean to claim its fame as the leading innovation of the British Agricultural Revolution. To the contrary, in this work *B. napus* serves as a cross-section, of sorts, of the many different technologies of importance and their combining into systems of agronomic design. As this study has shown, *B. napus* is unique for its frequent debut in the practice of each of these and other innovations. As a diverse design element, the plant serves as a focal point of period technology combining. To recap the findings of this study, *B. napus* was integrated with Jethro Tull's mechanical seed drill and horse-hoe innovation at a time when Tullians believed that air was the only food for the soil and warned against manuring, fallowing, and rotation. The blasphemous combining of Tull's machines with plant technology such as *B. napus* facilitated the more rapid planting of robust fodders. This, in turn, integrated livestock into arable land and increased production of yields in terms of both head of cattle or sheep and crops per acre. *B. napus* meal produced as a byproduct from the oil crushing mill was also drilled as a manure to control wireworm and other pests. This integrated an industrial waste back into the local soil. Such techniques supported better crops of turnips, which were so often drilled and horse-hoed but also suffered from crop failure on poor soils and in cold seasons. *B. napus* thrived in these conditions.

One of the crop's most important contributions as a form of agricultural improvement was as a winter feed for sheep and cattle during a time when animals were often slaughtered in the late fall for the problem of their pending starvation during the dark months. Combinations of *B. napus* and turnips were a robust winter feed and green fallow for grazing. Such innovations paved the way for the Norfolk Rotation, which included *B. napus* in proper and modified four to six course designs. The larger herds supported by the design were cycled through the *B. napus* planting to increase manure contributions. Finally, combinations of all of these applications facilitated the more rapid conversion of marshes and moor to arable, however the rotation of grazing land with planted arable also benefitted from the incorporation of *B. napus* into the package of drilling. These convertible husbandry designs facilitated enclosure of the commons and thus integrated the manure from saturated grazing fields to more deplete arable lands. With the more flexible designs made possible by fodder innovations, farmers enjoyed larger herd sizes and more control over manure inputs.

While such case studies of innovation do not add up to national trends or answer questions about the scale of *B. napus* adoption, it is clear that the plant's ability to help suppress soil pests, extend the fodder season, and diversify feed stocks was environmentally important to regions undergoing intensification. When increasing the acreage of monoculture and the number of successive rotations, the risk of pest infestation also rose. The pressure to expand planting into poor soils also called for pest-resistant strategies that thrived on sandy, dry, and waterlogged sites. Even if *B. napus* was only one strategy used to help resolve these specialized challenges, it would have been instrumental at the small scale. Though preliminary findings in this work show that *B. napus* was likely planted for improvement in nearly every county in England, Scotland, and Wales, future studies must use more traditional methods such as samples of regional inventories to aggregate evidence of geographic diffusion and the frequency of planting in terms of the number of farms and the total acres planted with *B. napus*. Models that back-apply modern estimates of pathogen suppression might be used to illustrate the potential environmental impacts.

Similarly, the problem of Britain's trade dependency on Irish and other food imports must be resolved as part of any larger narrative about the British Agricultural Revolution. Brinley Thomas argues that imports from Ireland of beef, butter, and pork increased by as much as 700 percent between 1760 to 1800.[5] For Thomas, the British Agricultural Revolution culminated in import dependency, though he does not clarify the extent to which English exports balanced this trade. Joan Thirsk shows that as early as the late seventeenth century English and Irish cloth and butter were often imported to France and Holland as affordable second or third-tier products to feed the ordinary families of an international consumer base. By purchasing more affordable English goods for the lower classes, France and Holland developed lucrative export routes for their higher quality fabrics and butters.[6] It is unknown whether England

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[5] Brinley Thomas, "Feeding England During the Industrial Revolution: A View From the Celtic Fringe," *Agricultural History* 56, no. 1 (Winter 1982), p. 335.
[6] Joan Thirsk, *Economic policy and projects : the development of a consumer society in early modern England* (Oxford: Clarendon Press, 1978), p. 136.

similarly exported the fruits of late eighteenth century improvement while importing cheaper food stuffs from Ireland to feed the working classes. Such complex economic relationships were prevalent long before the late eighteenth century dependencies on Irish meat and cereals that Thomas describes. Because these complex co-dependencies of the seventeenth century served as a baseline for later economic growth, we cannot assume that a greater dependency on Irish meat or cereal in the late eighteenth century necessarily indicates patterns of scarcity in England. It is clear that yields per acre per worker did increase over the long eighteenth century.

The late nineteenth century is an entirely different story. It is nearly indisputable that the late British Empire both suffered and benefitted from trade dependency on a globalized food supply chain. After Britain repealed the Corn Laws in 1846, English food imports began to exceed its exports by a large margin. "Most of these imports were taken in food and in other primary commodities [like cotton]. In order to purchase food overseas, England allowed its own agriculture to run down," writes Avner Offer.[7] Britain invented the global food system by shifting from self-sufficient farming to an outsourcing of much of its food supply. Domestic farmers also faced increasing competition from cheap food imports from Canada, the United States, and Ireland. Even the livestock industry proved vulnerable to new global markets in beef and mutton.

This late nineteenth century period falls outside the scope of the current study because the globalized supply chain offered new sources of oil for textile finishing. *B. napus* was rarely documented on farms in the twentieth century until scientists bred varieties for cooking oil that lacked the unpalatable erucic acid in the 1980s. Further research will be needed to fit *B. napus* into this chronology of late imperial trade dependency. However during the prior centuries,

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[7] Avner Offer, *The First World War, An Agrarian Interpretation* (Oxford England : New York: Clarendon Press; Oxford University Press, 1989), p. 3-4.

England was both an importer and exporter of rapeseed. Even despite England's on-going problem of sourcing oil for textile finishing during times of increased demand, my cursory review uncovered anecdotal evidence that Norfolk ports may have exported as much as 2,500 quarters a year of rapeseed in the 1790s.[8] This record from the Custom-House found its way into the *General Views* because "the four Norfolk ports export[ed] as much corn as all the rest of the Kingdom put together," according to John Holt, who penned the Board of Agriculture survey for the County of Lancaster.[9] Additional primary source research of customs archives will undoubtedly uncover more evidence of both *B. napus* seed and oil imports and exports.

Such trade dynamics complicated the relationship between domestic supply and demand. In fact, as early as the sixteenth century England faced the problem of rapeseed exports during times of increased domestic demand. Joan Thirsk describes Sir Thomas Gresham's difficulties securing 400-500 quarters of rapeseed a year from growers in Lincolnshire. He worked with his son-in-law, Nathaniel Bacon, to negotiate the deal. The problem was that "growers there already shipped 2,000 quarters a year to Flanders from Boston and King's Lynn," writes Thirsk. Gresham hoped to intercept some of this exported seed to crush at his mill in London, but the larger story suggests this was easier said than done.[10] Initially, Gresham and Bacon failed to close a deal for even 100 quarters of rapeseed, and Thirsk implies that competition from continental markets limited the flow of domestic seed to regional mills.[11] Like the late

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[8] John Holt, *General View of the Agriculture of the County of Lancaster: With Observations on the Means of Its Improvement*, ed. Board of Agriculture (G. Nicol, Pall-Mall, bookseller to His Majesty, and to the Board of Agriculture; and sold, 1795), p. 204.

[9] Holt, *General View of the Agriculture of the County of Lancaster: With Observations on the Means of Its Improvement*, p. 200-05.

[10] Joan Thirsk, *Alternative agriculture: a history from the Black Death to the present day* (Oxford: New York : Oxford University Press, 1997), p. 73-8.

[11] In 1655 Samuel Hartlib wrote in *His Legacy of Husbandry* that ten quarters of rapeseed was roughly eighty bushels. Samuel Hartlib, *His legacy of husbandry wherein are bequeathed to the common-wealth of England, not onely Braband, and Flanders, but also many more outlandish and domestick experiments and secrets (of Gabriel Plats and others) never heretofore divulged in reference to universal husbandry, With a table shewing the general*

eighteenth century numbers from the ports of Norfolk, this much earlier example suggests that rapeseed import and export histories do not necessarily map to patterns of demand. Even in the late sixteenth century, when Spanish olive oil supplies were under threat due to inflation and oil scarcity drove new investment in seed crushing, it is clear that valuable rapeseed was still sometimes shipped to the continent even despite domestic competition for purchase contracts. This case example serves as a warning that we cannot draw assumptions about surplus from export patterns nor conclude that trade dependency on foreign imports signaled domestic scarcity.

Future research will also explore the possibility of colonial American oilseed exports to England, as the oilseed exchange has long been neglected in favor of studies of sugar, cotton, and mast. Ken Pomeranz argues that colonial development offered the Crown greater leverage over its critical imports as the colonies required metropolitan manufactures, medicines, and investment support.[12] Though American imports did not feed the industrial masses, colonial natural resources and raw material inputs may have offset strain on English crop fields. Greater numbers of domestic acreage in England would have otherwise been dedicated to flax for linen and the production of other organic resources needed for industrial growth.

The history of *Brassica* seed importation for oilseed crushing may not settle the grand debate over the timeline of the emergence of Britain's globalized supply chain. However it is clear that England and Scotland imported large amounts of seed from the continent for crushing even while *B. napus* became more widely planted on farms of all sizes. Imports from abroad would have externalized the localized nature of cradle-to-cradle production. Though it is also

contents or sections of the several augmentations and enriching enlargements in this 3rd ed. (London: Printed by J.M. for Richard Wodnith ... 1655), p. 272.

[12] Kenneth Pomeranz, *The Great Divergence : Europe, China, and the Making of the Modern World Economy*, (Princeton, N.J.: Princeton University Press, 2000), p. 242-63.

clear that farmers grew *B. napus* because it served as an ideal fodder and re-shot into an oilseed crop after grazing. *B. napus* was a successful local crop with multiple inputs to localized livestock, soap, lighting, textile production, and soil manuring. Further studies will question the relative amount of imported and domestically grown seed with the help of parliamentary reports.

I focused the current project on the very different questions of the environmental impacts of local alternative foddering during the British Agricultural Revolution. The model used by eighteenth century farmers is strikingly similar to the tactics employed today in 21st century California, Sweden, England, Germany, and other locations. Modern farmers recharge the soil by planting rapeseed during the fallow season, but they also profit from the crop by selling the seed from the harvest to an oil press. To recap the scientific framework underpinning this dissertation, the brown flaky meal left from oil crushing has been tested in field and potting studies for its benefits in soil pathogen suppression, and pellets consisting of mixtures of crushed Brassica seeds are used as a soil amendment. Today Brassica seed meal is used in place of chemicals that entirely sterilize the soil, wiping out all forms of life. Unlike these kill-all, synthetic chemical biocides that also rid the soil of beneficial and benign microbes, and create a vacuum for invading pathogens to grow without competition, Brassica meals are not entirely comprehensive. While seed meal technologies do not always completely rid the soil of the disease problem, they often bring about comparable reductions in the pathogen over time while also increasing beneficial microbes and soil nutrients. Soils continue to improve over time while chemically treated soils return to the baseline state of disease. As to how historical studies might benefit modern techniques, period sources suggest that soil amendments might be more efficacious if the oil concentration were modified. Historical cakes and meals likely contained greater concentrations of oils, and farmers modified presses to preserve oil in the byproduct.

Success of the soil amendment treatment might also be improved with cover cropping, green fallowing, rotation, and even convertible husbandry for manure inputs from animals that graze rapeseed fields.

Though there are many questions left unanswered and more research to be conducted, these findings highlight the potential for eighteenth century studies of agricultural technology to serve as an applied historical study. The soil cultivation which determines the success and failure of amendments can be observed over generations through the archives. While historical practices do not directly map to modern fields, they might inform researchers and growers in remaking age-old traditions. Similarly, the application of modern science to historical fields sheds new light on the structure of economic and environmental change. Turnips, clover, and legumes are not attributed with pathogen suppression mechanisms—at least not at the industrial scale—and based on rapeseed's more potent impacts, it is likely that it had a great impact on early modern soils. According to a wide and diverse array of historical sources, rapeseed helped increase productivity over short time-periods, and it was used to handle a wide variety of growing problems and conditions. Rapeseed was grown in the worst of all soils with very little effort, and within a season or two, cash crops could be planted. By focusing on these historical integrated agronomical designs, we shift the debate from novelty, introduction chronologies, and the difficulties of proving the density and geography of technology disbursal. Instead, the over-all evolution and sophistication of integrated farm design can be seen as part of the structure of the British Agricultural Revolution.

APPENDICES

APPENDIX I: Methyl Bromide Use in California, 2017

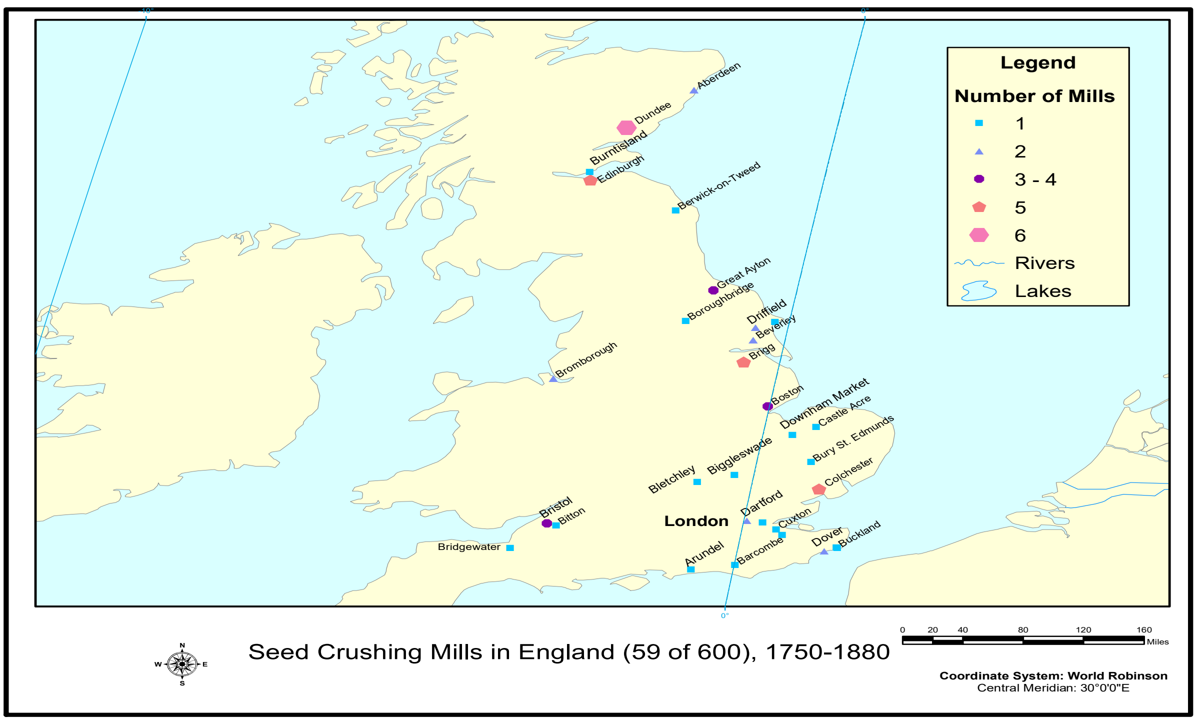
To estimate the current use of Methyl Bromide, I focused on California usage as the California Department of Pesticide Regulation offers pesticide use data via a downloadable Pesticide Use Report. On May 9, 2020 I ran a querry using the California Pesticide Information Portal Application "Querry Pesticide Uea Report." Data was retrieved for: crop (Strawberry); chemical (Methyl Bromide); year (2017); counties (all 58 listed counties in California). From the data, about 8,517 pounds of Methyl Bromide was ued each year. Application occurred in only two counties—Santa Cruz and Sutter. It is likely that use in California is lower than in other states that do not report or make reporting accessible to the public. Methyl Bromide was largely phased out of use in the European Union per the terms of the 1987 Montreal Protocol, however the United States has appealed for critical use exemptions granted for fruit, tomato, and other applications. While Methyl Bromide is beneficial for killing pests like wireworms, fungi, and some weeds all in one application, it is criticized for causing stratospheric ozone depletion and for its toxicity to farm laborers. It is also thought to encourage the re-colonization of the soil by opportunisit colonizers by so effectively eradicating all life in the soil, including the microorganisms that compete for resources and directly prey upon disease organisms.
See: https://calpip.cdpr.ca.gov/county.cfm?ds=PUR.

ADJUVANT	YEAR	DATE	COUNTY NAME	COMTRS	SITE NAME	PRODUCT NAME	POUNDS PRODUCT APPLIED	CHEMICAL NAME	POUNDS CHEMICAL APPLIED	AMOUNT TREATED	UNIT TREATED	AERIAL GROUND INDICATOR
NO	2017	01-JUL-17	SANTA CRUZ	44	STRAWBERRY (ALL OR UNSPEC)	METHYL BROMIDE 100	240.3	METHYL BROMIDE	240.3	180869	U	
NO	2017	01-AUG-17	SANTA CRUZ	44	STRAWBERRY (ALL OR UNSPEC)	METHYL BROMIDE 100	363	METHYL BROMIDE	363	187965	U	
NO	2017	01-SEP-17	SANTA CRUZ	44	STRAWBERRY (ALL OR UNSPEC)	METHYL BROMIDE 100	301.3	METHYL BROMIDE	301.3	206210	U	
NO	2017	01-MAY-17	SANTA CRUZ	44	STRAWBERRY (ALL OR UNSPEC)	METHYL BROMIDE 100	108.5	METHYL BROMIDE	108.5	65354	U	
NO	2017	01-JUN-17	SANTA CRUZ	44	STRAWBERRY (ALL OR UNSPEC)	METHYL BROMIDE 100	239.8	METHYL BROMIDE	239.8	180199	U	
NO	2017	01-OCT-17	SANTA CRUZ	44	STRAWBERRY (ALL OR UNSPEC)	METHYL BROMIDE 100	54.1	METHYL BROMIDE	54.1	17145	U	
NO	2017	19-MAY-17	SANTA CRUZ	44M12S01E12	STRAWBERRY (ALL OR UNSPEC)	TERR-O-GAS 67	1645	METHYL BROMIDE	1102.15	4.7	A	F
NO	2017	16-AUG-17	SANTA CRUZ	44M12S01E13	STRAWBERRY (ALL OR UNSPEC)	TRI-CON 50/50	1050	METHYL BROMIDE	525	2.8	A	F
NO	2017	20-MAR-17	SUTTER	51M13N04E13	STRAWBERRY (ALL OR UNSPEC)	TERR-O-GAS 67	2765	METHYL BROMIDE	1852.55	7.9	A	F
NO	2017	18-MAR-17	SUTTER	51M13N04E13	STRAWBERRY (ALL OR UNSPEC)	TERR-O-GAS 67	1750	METHYL BROMIDE	1172.5	5	A	F

6.1 *Methyl Bromide Use Report, California Department of Pesticide Regulation*

APPENDIX II: Oil Crushing Mills in Britain, 1790-1865

I used Google Earth to geocoordinate the 600 of 640 seed mills listed for oil crushing from 1790 to 1865 in *History of Seed Crushing in Great Britain* by Harold W. Brace. ArcGIS was used to plot the dispersal of the first 59 of the 600 mills. As mills were listed alphabetically by locality, the selection of the first 59 mills in the geocoordinate spreadsheet is a good sample of the larger distribution. Disbursal is centralized along the East Coast of England and Scotland, which suggests continental imports of seed for crushing. Unfortunately due to COVID19 I was unable to gain access to the ArcGIS labs on campus during the end of winter, spring, and summer quarters to complete additional maps showing the full 600 mills.



6.2 *Seed Crushing Mills in England, 1750-1880*

APPENDIX III: Dispersal of Rapeseed by County

Table 6.2 County Surveys that Document Brassica Napus (Rapeseed) for Improvement General Views, Board of Agriculture

Kingdom	County	1st Edition	2nd Edition
England	Bedfordshire	Y	
England	Berkshire	Y	
England	Buckinghamshire	Y	
England	Cambridgeshire	Y	
England	Palatine of Chester	Y	
England	Cheshire	Y	
England	Cornwall	Y	
England	County Durham	Y	
England	Cumbria/Cumberland	Y	
England	Derbyshire	Y	
England	Devon	Y	N
England	Dorset	Y	N
England	East Riding of Yorkshire	Y	Y
England	Essex	Y	Y
England	Gloucestershire	Y	
England	Wight	Y	
England	Hants	Y	
England	Hereford	Y	
England	Hertfordshire	Y	
England	Huntingdon	Y	N
England	Isle of Wight	Y	
England	Kent	Y	
England	Lancashire	Y	
England	Lancaster	Y	
England	Leicestershire	Y	
England	Lincolnshire	Y	Y
England	Middlesex	Y	N
England	Norfolk	Y	Y
England	North Riding Yorkshire	Y	

England	Northamptonshire	Y	Y
England	Nottinghamshire	Y	
England	Oxfordshire	N	
England	Rutland	Y	
England	Salop	N	
England	Shropshire	Y	
England	Somerset	Y	
England	Staffordshire	Y	
England	Suffolk	Y	
England	Surrey	Y	Y
England	Sussex	Y	
England	Warwickshire	Y	Y
England	Wilts	Y	
England	West Riding Yorkshire	Y	
England	Westmoreland	N	
England	Worcester	Y	N
Scotland	Aberdeenshire	Y	N
Scotland	Angus	N	N
Scotland	Argyll	Y	N
Scotland	Ayrshire	Y	
Scotland	Banffshire	Y	N
Scotland	Berwickshire	Y	
Scotland	Bute	Y	
Scotland	Caithness	Y	
Scotland	Clackmannanshire	Y	
Scotland	Dumfries	Y	N
Scotland	Dunbartonshire	Y	
Scotland	East Lothian	Y	
Scotland	Elgin or Moray	N	
Scotland	Fife	Y	N
Scotland	Galloway	Y	N
Scotland	Highland	Y	
Scotland	Inverness	Y	
Scotland	Kincardineshire	Y	N
Scotland	Kinross	Y	N
Scotland	Mid Lothian	Y	

Scotland	Moray	Y	N
Scotland	Perth & Kinross	Y	N
Scotland	Peebles	N	
Scotland	Renfrewshire	N	N
Scotland	Stirlingshire	Y	N
Scotland	Tweedale	N	
Scotland	West Lothian	N	
Scotland	Western Isles	Y	

APPENDIX IV: Archives Visited for Research

United Kingdom

Aberdeen University Library, Special Collections & Museums
The Sir Duncan Rice Library,
Bedford Road,
Aberdeen,
AB24 3AA

Blair Castle, Archives
Blair Castle Estate Ltd.,
Blair Atholl, Pitlochry
Perthshire
PH18 5TL

Cambridgeshire Archives
The Dock
Ely
CB7 4GS
(Formerly based at Shire Hall, Cambridge).

Glocestershire Archives
Clarence Row,
Gloucester
GL1 3DW

Hull History Centre
Worship St,
Hull
HU2 8BG

Huntingdonshire Archives
Princes Street
Huntingdon
PE29 3PA

Lambeth Palace Library
Bishop's
London
SE1 7JU

University of Leicester Special Collections
University Library
University of Leicester
University Road
Leicester
LE1 7RH
National Archives London
Bessant Dr.
Kew, Richmond
TW9 4DU

National Library Scotland
George IV Bridge
Near Greyfriars Kirkyard
92 Cowgate
Edinburgh
EH1 1JN

National Records of Scotland
2 Princes St.
Edinburgh
EH1 3YY

Oxfordshire Archives
St Lukes Church
Temple Rd, Cowley
Oxford OX4 2HT

Royal Society Archives
6-9 Carlton House Terrace
London
SW1Y 5AG

Shakespeare Birthplace Trust
20 Henley St.
Stratford-upon-Avon
CV37 6QW

Shropshire Archives
The Shirehall
Abbey Foregate
Shrewsbury
SY2 6LY

Treasure House
Champney Rd.
Beverley
HU17 8HE

University of Glasgow Special Collections

Archives & Special Collections
University of Glasgow Library
Level 12 Reading Room
Hillhead Street
Glasgow
G12 8QE

Archives & Special Collections
University of Glasgow
13 Thurso Street
Glasgow
G11 6PE

University of Oxford

Balliol College Special Collections
St. Cross Church
University of Oxford
St.Cross Rd.
Oxford
OX1 3TP

Bodleian Library Special Collections
Weston Library
University of Oxford
Broad St
Oxford
OX1 3BG

Brasenose College Library
Brasenose College
University of Oxford
Radcliffe Square
Oxford
OX1 4AJ

Codrington Library
All Souls College
University of Oxford
University of Oxford
High St.
Oxford
OX1 4AL

Fellows Library
Jesus College
University of Oxford
Turl St.
Oxford
OX1 3DW

History of Science Museum
University of Oxford
Broad St.
Oxford
OX1 3AZ

Lincoln College Library
Lincoln College
University of Oxford
Turl St.
Oxford
OX1 3DR

Merton College Library
University of Oxford
Merton St.
Oxford
OX1 4JD

St. Edmund Hall Special Collections
University of Oxford
Queen's Ln.
Oxford
OX1 4AR

Trinity Library
Trinity College
University of Oxford
Broad Street
Oxford
OX1 3BH

University College Library
University College
Oxford
OX1 4BH

Worcester College, The Special Collections
Worcester College
Walton Street
Oxford
OX1 2HB

Warwickshire County Record Office
Priory Park, Cape Rd
Warwick
CV34 4JS

Wiltshire and Swindon History Centre
Cocklebury Rd.
Chippenham
SN15 3QN

United States of America

John Carter Brown Library
Brown University
94 George St, Providence, Rhode Island
02906

Folger Shakespeare Library
201 E Capitol St SE
Washington, District of Columbia
20003

Smithsonian Institution
National Museum of Natural History
National Anthropological Archives
Museum Support Center
4210 Silver Hill Road
Suitland, Maryland
20746

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