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GRAIN YIELDS ON ENGLISH DEMESNES AFTER THE BLACK DEATH

Bruce M. S. Campbell*

The Black Death of 1348–49 constitutes proportionately the single greatest demand-side shock in English agricultural history. At a stroke, it reduced by at least forty per cent the size of the population to be fed and delivered windfall gains in living standards to those who survived, enabling them the better to indulge their dietary preferences.¹ On the supply side, it transformed factor costs, raising the price of labour but reducing the prices of land and, as money supply *per capita* increased, capital.² Rarely, if ever, have agricultural producers been challenged by such profound and rapid economic changes. Moreover, the prolonged postponement of any sustained demographic recovery ensured that these changes endured long after the original precipitating event had passed.³

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¹ For an extensive review of the English evidence of mortality in the Black Death and the conclusion that 'the general population mortality in England appears to have been of the order of magnitude of 62.5 per cent', see Benedictow, *The Black Death*, pp. 342–79 (p. 377). Hatcher, 'England in the Aftermath', pp. 8–9, favours a more modest excess mortality rate of between forty and fifty per cent, while Aberth, *From the Brink of the Apocalypse*, pp. 127–28, plumps for forty to sixty per cent. For post-plague dietary developments see Dyer, *Standards of Living*, pp. 158–60, and for the production response, Campbell, 'Matching Supply to Demand'.

² Clark, 'Long March of History', pp. 99–100; Clark, 'The Cost of Capital'; Epstein, *Freedom and Growth*, pp. 61–62.

³ Hatcher, *Plague, Population, and the English Economy*, describes the one hundred and fifty years which followed the Black Death as 'the longest period of declining and stagnant population in recorded English history' (p. 11).

At the same time, husbandmen had to contend with significant shifts in growing conditions, as the agriculturally benign conditions of the Medieval Warm Period gave way to the cooler, stormier, and more variable weather of the Little Ice Age.⁴ According to a recent reconstruction by C. Loehle and J. H. McCulloch, global temperatures cooled from the 1250s to the 1350s, briefly recovered during the second half of the fourteenth century (when temperatures were temporarily restored to levels not experienced since the mid-thirteenth century), and then cooled again during the first half of the fifteenth century to a marked low point in the 1450s (fig. 13A). After a further brief respite, temperatures plunged to their Little-Ice-Age minimum from the 1590s to the 1690s. World tree growth, which has been reconstructed by M. G. L. Baillie at a far higher level of chronological resolution, echoed these trends, as warmer temperatures boosted growth and cooler temperatures depressed it (fig. 13A). Thus, the 1250s witnessed a notable temporal peak in tree growth, the 1290s and 1350s pronounced troughs, the 1380s a lesser peak, and the 1460s a further trough.⁵

The first half of the fifteenth century seems to have been a negative tipping point for both temperatures and trees (fig. 13A) and this coincided with a major shift in the sea-level pressure gradient between Iceland and eastern Siberia. The advent of lower pressure over Iceland and higher pressure over Siberia (fig. 13B) generated more intense atmospheric circulation over the North Atlantic, resulting in colder and more unsettled winter conditions over northwestern Europe. Growing conditions for grain consequently became both less favourable and more unstable. L. D. Meeker and P. A. Mayewski consider this to have constituted 'the most rapid onset of any such event recorded in the North Atlantic region over the last 10,000 years'.⁶

The economic and environmental contexts of grain production thus altered in fundamental ways following the Black Death. An earlier generation of historians, lacking the insights into changing environmental conditions since provided by scientists, tended to couch discussion of late medieval grain yields in terms of land availability and quality, soil nutrient levels, technology, investment, and

⁴ The literature on the transition from the Medieval Warm Period to the Little Ice Age is large and fast expanding; see for example, Grove, *The Little Ice Age*; Pfister, Schwarz-Zanetti, and Wegmann, 'Winter Severity in Europe'; Higgitt, 'A Brief Time of History'; Meeker and Mayewski, 'A 1400-Year High-Resolution Record'; Cook, Esperb, and D'Arrigo, 'Extra-Tropical Northern Hemisphere'.

⁵ For a fuller discussion of the dendrochronological evidence as it relates to the fourteenth century, see Baillie, *New Light on the Black Death*, pp. 15–39.

⁶ Meeker and Mayewski, 'A 1400-Year High-Resolution Record', p. 263.

Figures 13A and 13B. Evidence of macro environmental changes *c.* 1200 to *c.* 1500: world tree growth, global temperatures, and sea level pressure in Eastern Siberia and Iceland

Sources and methods:

World tree growth (five-year smoothed trend): master chronology which combines ‘national’ chronologies for the Aegean, Polar Urals, Fennoscandia, temperate Europe (oaks), North America (bristlecone pine), Chile and Argentina, Tasmania, and New Zealand (data supplied by Mike Baillie).

Global temperatures (thirty-year smoothed trend): Loehle and McCulloch, ‘Correction to: “A 2000-Year Global Temperature Reconstruction”’ (data available at <<http://www.econ.ohiostate.edu/jhm/AGW/Loehle/LoehleMcC.txt>> [accessed 23 July 2009]).

Sea level pressure (three-year resampled GISP 2 ssNa and log(nssK) series calibrated with and extending the instrumental record 1899–1986): Meeker and Mayewski, ‘A 1400-Year High-Resolution Record’, p. 261.

labour inputs.⁷ Drawing upon the copious statistical information contained in many thousands of extant manorial accounts, they demonstrated that following the Black Death demesne managers progressively reduced the amount of tillage kept in cultivation and removed a good deal of inferior land from grain production, so that the average quality of land under crop should have risen. Some of this former arable was laid down to grass, so that (except when dairies were leased out and sheep flocks centralized) most demesnes maintained and even increased the numbers of animals stocked, as was consistent with a strengthening relative demand for pastoral products. Stocking densities consequently rose, to the ecological benefit of the balance struck between horn and corn production and on-the-farm recycling of nutrients.⁸

These developments were accompanied by changes in the production mixes of crops and livestock and modifications to rotations, as producers responded to changing consumer preferences and production costs. There was a retreat from the more capital and labour intensive forms of husbandry, as witnessed by the fact that seed was often sown more thinly and such manually demanding tasks as weeding, manuring, and marling were either scaled down or abandoned. Customary labour services (already of marginal importance on many demesnes) became harder to collect and probably were more grudgingly performed, especially following the Peasants' Revolt of 1381, so that within a generation of the Black Death there was a general substitution of hired for servile labour by all but the most conservative of landlords.⁹ Thereafter, as higher wages and lower prices squeezed profit margins ever harder, so demesne managers did all they could to economize on labour.

If worsening worker : employer relations and reduced labour inputs per unit area are likely to have had an adverse effect upon grain yields, withdrawing cultivation from inferior soils, stocking more livestock, and reforming rotations should have worked to the ecological advantage of arable production and benefit of *average* grain yields. Which of these countervailing tendencies prevailed?

⁷ As most notably and influentially in the case of Postan, *The Medieval Economy and Society*, pp. 41–72, Brenner, 'The Agrarian Roots of European Capitalism', pp. 232–36.

⁸ Fulllest documentation of these developments was provided by David L. Farmer, see n. 11 below.

⁹ For the limited importance of labour services before the Black Death see Campbell, 'The Agrarian Problem', pp. 36–39. For their subsequent decline the classic study is Hilton, *The Decline of Serfdom in Medieval England*. The relative efficiencies of waged and servile labour in the late fourteenth century are evaluated in Stone, 'Productivity of Hired and Customary Labour'. An example of the replacement of servile with waged labour is Dyer, *Lords and Peasants*, pp. 120–21, 140–43.

Figures 14A and 14B. Westminster demesnes: indexed trends in cropped area, livestock units, stocking densities, percentage legumes, and grain seeding rates, 1275–1404

Sources and methods: Based on David L. Farmer's transcripts for the demesnes of Turweston (Buckinghamshire); Birdbrook, Feering, Kelvedon (Essex); Bourton-on-the-Hill, Sutton-under-Brailes, Todenham (Gloucestershire); Aldenham, Kinsbourne, Stevenage, Wheathampstead (Hertfordshire); Westerham (Kent); Ashford, Eye/Eybury, Hendon (Middlesex); Islip (Oxfordshire); Pyrford (Surrey) preserved in Saskatoon, USaskArch., 'The Papers of David Farmer'. The assistance of the archivists at the University of Saskatchewan is gratefully acknowledged. Intermittent data series for these seventeen demesnes of have been combined into single continuous series for the estate as a whole using a logged regression method recommended by Gregory Clark. All series are indexed against their respective means for the period 1300–99. Livestock units have been calculated using the following weights: horses $\times$ 1.0; bulls, oxen and cows 1.2; immature cattle $\times$ 0.8; sheep $\times$ 0.1 (but note that Farmer's transcripts exclude swine).

No one has considered this issue more carefully or brought more data to bear upon it than the late David Farmer, who painstakingly extracted and analysed 7760 yield observations from the pipe rolls of the bishopric of Winchester for the period 1349–1453 and a further 4080 yields from the manorial accounts of Westminster Abbey for the years 1274–1404.¹⁰ Nevertheless, the results obtained by these protracted labours perplexed him. Thus, in the case of the Westminster estate, its seventeen manors were adopting a whole raft of practices, which, other things being equal, should have improved their grain yields. The monks reduced the sown lands of their demesnes by expanding fallows, converting some of the more marginal land to pasture, and letting out portions to tenants. By 1348 they already had twenty-five per cent less land under crop than *c.* 1290 and by 1400 this area had shrunk by a further twenty per cent (fig. 14A). Over the same period they expanded the share of the cropped acreage sown with nitrifying legumes, from barely five per cent *c.* 1290, to fifteen per cent by 1348, and eventually over twenty per cent by 1400 (fig. 14B). Meanwhile, from the 1330s modest economies were made in the rate at which seed was sown per acre (fig. 14B) and this policy was maintained more-or-less for the rest of the fourteenth century. The estate had been badly hit by the great cattle plague of 1319–20 but following that disaster flocks were expanded and herds patiently reconstructed so that by the eve of the Black Death livestock numbers had been returned to their pre-pandemic levels (fig. 14A). Subsequently they were raised still higher so that at their peak in the 1360s and 1370s the ratio of livestock to sown acres was double that prevailing when arable cultivation had been at maximum stretch in the late thirteenth century (a period when Farmer believes soil-nutrient deficiency arising from under-manuring had become a problem on many of these demesnes). To counter losses from fraud and embezzlement, the monks also instituted stricter accounting and auditing practices, demanding more detailed information and fuller explanations of any shortfall in output.¹¹

Yet, to Farmer's surprise, all that happened as a result of these not inconsiderable adjustments was that wheat yields per seed emerged a little lower at the end of the fourteenth century than they had been during the intensive cultivation of a century earlier, while barley yields improved by around a fifth and oats yields by about a third (fig. 15).¹² Overall, there was a gain of approximately ten per cent in

¹⁰ Farmer, 'Grain Yields on the Winchester Manors'; Farmer, 'Grain Yields on Westminster Abbey Manors'; Farmer, 'Crop Yields, Prices and Wages'.

¹¹ Stern, *A Hertfordshire Demesne*, ed. by Thornton, pp. 181–83.

¹² Farmer, 'Grain Yields on Westminster Abbey Manors', p. 343.

Figures 15A–15D. Westminster demesnes: yields per seed of wheat, barley, oats, and wheat (barley/oats) gross of tithe and net of seed, 1275–1405

Sources and methods: Estate-level trends have been derived using the sources and method specified in Figure 14. Tithe is assumed to have comprised one-tenth of the total harvest, gross of seed. Wheat (Barley/Oats) yield = (Wheat yield $\times$ 0.5) + (Barley yield $\times$ 0.25) + (Oats yield $\times$ 0.25). All series are indexed against their respective means for the period 1300–49. Linear regression lines are added to show trends across the period as a whole.

grain yields per seed on the Westminster demesnes over the course of the fourteenth century, a far from impressive improvement given the magnitude of the changes that had been made to the scale and composition of production (fig. 14). Indeed, at the opening of the fifteenth century, in the final years of direct management on this estate, yields actually sank below the average for the previous century. Across this entire period yields per seed were decidedly 'sticky' and neither at the level of the individual demesne nor the estate as a whole did adoption of more beneficial husbandry practices necessarily translate into better yields per seed.

Developments on the estate of the bishops of Winchester were broadly similar, apart from the lack of any marked expansion in legume cultivation.¹³ Arable production steadily contracted. The mean sown acreage per demesne fell from a maximum of over two hundred and sixty acres (one hundred and five hectares) in the 1230s, to around two hundred acres in the 1290s, one hundred and forty-five acres on the eve of the Black Death, one hundred and five acres at the opening of the fifteenth century, and, eventually, ninety to ninety-five acres in the 1450s and 1460s.¹⁴ Since there was little corresponding reduction in livestock numbers until the fifteenth century (when across the estate as a whole livestock numbers trended gently downwards, falling by approximately a third between the mid-1390s and mid-1430s), stocking densities rose significantly. By 1362–64 the ratio of livestock to cropped acres had risen to almost double its immediate pre-Black Death level and by 1395–97 it was one hundred and thirty per cent above that level; in the 1430s it was still well above the level of a century earlier.¹⁵ The potential for enhanced cycling of on-the-farm nutrients to the benefit of soil fertility and crop yields was therefore considerable, especially as sheep (extensively used for folding and thereby manuring the arable) were the principal beneficiary of these pastoral gains.¹⁶ Yields per seed of wheat, the most commercialized and valuable

¹³ Farmer, 'Crop Yields, Prices and Wages', p. 132; Farmer, 'Grain Yields on the Winchester Manors', pp. 564, 566.

¹⁴ Calculated with the kind permission of Jan Titow from the transcripts and tabulations contained in Winchester, HantsRO, 97M97 ('Titow Research Papers').

¹⁵ Livestock units per one hundred cropped acres per Winchester demesne were: 1300–24, 46; 1325–49, 43; 1362–64, 84; 1377–79, 96; 1395–97, 100; 1409–11, 96; 1420–22, 91; 1433–35, 82. The livestock units are those employed by Jan Titow and David Farmer, i.e. *equines* and *bovines* 1.00 units each, *ovines* 0.25 units each (*porcines* are excluded), and have been calculated from Titow, *Winchester Yields*, pp. 136–39; Farmer, 'Grain Yields on the Winchester Manors', p. 563.

¹⁶ In the 1330s there had been around 15,000 demesne sheep on the episcopal estate; by

crop, nevertheless registered no sustained improvement. On the contrary, from the close of the fourteenth century, they drifted steadily downwards to a level in the mid-fifteenth century a third lower than that achieved in the late thirteenth century. Barley yields initially fared better and rose by approximately twenty per cent over the course of the fourteenth century, only to subside and return to their late thirteenth-century level by the mid-fifteenth century. Oats yields alone displayed a significant and sustained improvement and over this same period gained by an impressive seventy-five per cent.¹⁷ That, however, was insufficient to offset the erosion of wheat and barley yields, so that across the two-hundred-year period 1270–1470 the combined yield of these three principal grains varied within ten per cent of the long-term mean and was no better in the 1450s than it had been in the 1320s.¹⁸ In Farmer's opinion 'the yield ratios and the yields per acre remained pitifully meagre'.¹⁹

How is the paradox of improved mixed-farming methods but scarcely improved grain yields to be explained? Did reductions in labour inputs (a variable not considered by Farmer) inhibit any recovery in yields? Did worsening weather — as the medieval Warm Period receded and the Little Ice Age advanced — offset the improved farming methods? Or was the seed sown botanically incapable of delivering better returns? Did higher yields, in fact, have to await the biological transformation of seed stocks? Moreover, just how representative are the Westminster and Westminister estates of the seignorial sector as a whole?

Levels and Trends in Grain Yields post-1340

Drawing on a national database of demesne yields, Tables 6 and 7 provide outline statistics of yields per seed, gross of tithe (estimated at one-tenth of the original harvest) and seed, for the four main crops of wheat, rye, barley, and oats for the successive fifty-year periods 1300–49, 1350–99, and 1400–49. Summary information is also given for yields on the Winchester and Westminster estates (the two main estates studied by Farmer). These are crude statistics, which have not

1369 there were almost 35,000 and the number of sheep per sown acre had increased fivefold: Stephenson, 'Wool Yield in the Medieval Economy', pp. 385–88.

¹⁷ Farmer, 'Grain Yields on the Winchester Manors', p. 565.

¹⁸ Aggregate trends calculated from the year-by-year and manor-by-manor yield data contained in Titow, *Winchester Yields*, and Saskatoon, USaskArch., 'The Papers of David Farmer'. For the individual yield observations, see Campbell, *Three Centuries of English Crop Yields*.

¹⁹ Farmer, 'Grain Yields on the Winchester Manors', p. 566.

been weighted by manor, county, region, or year, and are thus in part a function of the uneven geographical and chronological coverage of the data (fig. 16A).²⁰ Ninety-five per cent of these yield observations derive from demesnes in episcopal, conventual and collegiate ownership, for the simple reason that these estates are represented by the largest collections and longest runs of extant manorial accounts. Although 250 demesnes are represented in the database, less than half of these have data spanning more than twenty-five years. More useful for the purpose of constructing long-term chronologies of yields are demesnes with substantial runs of accounts: seventy-one demesnes have yield observations spanning at least fifty years and, of these, thirty-four have observations extending over more than a hundred years. All the best-documented demesnes belonged to the bishop of Winchester and, with the exception of Ebbesbourne in neighbouring Wiltshire and Brightwell in adjacent Berkshire, all (East Meon, Mardon, Ecchinswell, High Clere, Bishops Waltham, Overton, and Hambledon) were in Hampshire. Consequently, Hampshire eclipses all other counties in the quantity and chronological range of its recorded yields. Norfolk, the next best-represented county, has only a third Hampshire's number of yields. In descending order, Kent, Wiltshire, Hertfordshire, Berkshire, Suffolk, Essex, Buckinghamshire, and Somerset, are also reasonably well represented, largely reflecting the distribution of estates with the best collections of extant manorial accounts — the bishopric and cathedral priory of Winchester, Westminster Abbey, Canterbury Cathedral Priory, Norwich Cathedral Priory, Battle Abbey, Glastonbury Abbey, and the Abbey of Bury St Edmund's. Geographically, therefore, the yield data come almost exclusively from England's arable heartland, south of a line from the Wash to the Severn and east of the Exe.

As Tables 6 and 7 demonstrate, low to modest yields of two- to five-fold were the norm for all crops. Yields were consistently higher for winter-sown wheat and rye (Table 6) than spring-sown barley and oats (Table 7), with yields of wheat and oats diverging most, especially before the Black Death. Yields on the Westminster demesnes (which account for ten per cent of total observations — fig. 16A) were not significantly different from those in the country as a whole, except that wheat yields were below and barley yields above their respective national averages.²¹ The failure of the estate's wheat yields to improve following the Black Death was repeated at a national level, as was the modest but real improvement in the yield

²⁰ See Campbell, *Three Centuries of English Crop Yields*, for the scope and coverage of these yield observations by manor, estate, and county.

²¹ On the often striking differential between wheat and barley yields see, Farmer, 'Grain Yields on Westminster Abbey Manors', pp. 337–38.

Figures 16A and 16B. Winchester demesnes, Westminster demesnes, and all English demesnes: annual numbers of grain yield observations and trends in grain-yields per seed, 1340–1479

Sources and methods: The individual yield observations are those given in the database Campbell, *Three Centuries of English Crop Yields*. The Westminster, Winchester, all other estates, and English trends are seven-year moving averages indexed on their respective means for 1300–49 and have been derived using the logged regression method specified in figs 14A–14B. The national trend is the product of the eight regional sub-trends shown in figs 18A–18B. The indexed annual values for England, Westminster, and Winchester are given in Appendix 1.

of oats. Yields on the far larger and better documented Winchester estate (which accounts for fifty-one per cent of total English yield observations — fig. 16A) also display much the same size range and lack of any dramatic change of level or

Table 6. English wheat and rye gross yields per seed 1300–49, 1350–99, 1400–49
(with summary statistics for yields on the Winchester and Westminster estates)

Yield per seed (YPS) gross of tithe and seed	Wheat YPS 1300–49	Wheat YPS 1350–99	Wheat YPS 1400–49	Rye YPS 1300–49	Rye YPS 1350–99	Rye YPS 1400–49
< 1	0.3	0.2	0.2	1.0	1.3	2.0
1 – < 2	5.0	4.6	1.9	4.9	7.6	2.0
2 – < 3	17.2	22.9	15.0	13.5	21.3	19.4
3 – < 4	28.5	27.8	34.0	24.8	26.8	20.4
4 – < 5	22.5	22.0	27.3	24.3	22.0	26.5
5 – < 6	13.9	12.8	13.2	16.7	13.9	12.2
6 – < 7	6.7	6.1	5.2	8.0	3.0	7.1
7 – < 8	3.1	2.5	2.5	3.6	1.5	7.1
8 – < 9	1.5	0.7	0.5	2.3	1.3	1.0
9 – < 10	0.7	0.2	0.2	0.6	0.5	1.0
10	0.5	0.1	0.1	0.4	0.8	1.0
9+	1.2	0.3	0.2	1.0	1.3	2.0
England N	3226	3460	1221	905	395	98
<i>Winchester N</i>	<i>1553</i>	<i>1962</i>	<i>779</i>	<i>108</i>		
<i>Westminster N</i>	<i>406</i>	<i>409</i>		<i>116</i>	<i>14</i>	
England median	3.94	3.90	3.94	4.22	3.78	4.41
<i>Winchester median</i>	<i>4.22</i>	<i>4.15</i>	<i>3.93</i>	<i>4.74</i>		
<i>Westminster median</i>	<i>3.22</i>	<i>3.21</i>		<i>3.83</i>	<i>4.29</i>	
England mean	4.18	4.09	4.11	4.35	3.88	4.40
<i>Winchester mean</i>	<i>4.36</i>	<i>4.29</i>	<i>4.09</i>	<i>4.76</i>		
<i>Westminster mean</i>	<i>3.23</i>	<i>3.36</i>		<i>4.23</i>	<i>4.09</i>	
England Coef Var	38.37	35.45	31.54	39.09	41.35	11.60
<i>Winchester Coef Var</i>	<i>34.88</i>	<i>32.60</i>	<i>28.81</i>	<i>29.30</i>		
<i>Westminster Coef Var</i>	<i>34.97</i>	<i>34.35</i>		<i>54.69</i>	<i>22.08</i>	

Source: Campbell, *Three Centuries of English Crop Yields*.

frequency following the 1349 watershed, other than a similar improvement in the yield of oats. Farmer's conclusion that yields per seed changed little following the Black Death is therefore confirmed, and holds as valid for the second half-century following the plague as the first. Since yield observations are as abundant for the period 1350–99 as they had been for the years 1300–49, comparison between the two halves of the fourteenth century is statistically well founded: after 1400, however, the number of observations falls off dramatically, so that generalizations

Table 7. English barley and oats gross yields per seed 1300–49, 1350–99, 1400–49
(with summary statistics for yields on the Winchester and Westminster estates)

Yield per seed (YPS) gross of tithe and seed	Barley YPS 1300–49	Barley YPS 1350–99	Barley YPS 1400–49	Oats YPS 1300–49	Oats YPS 1350–99	Oats YPS 1400–49
< 1	0.3	0.7	0.3	1.5	1.1	0.4
1 – < 2	4.7	5.0	1.8	21.6	13.1	5.7
2 – < 3	22.3	18.0	15.3	47.4	39.0	30.1
3 – < 4	31.4	29.9	35.8	21.9	34.2	40.9
4 – < 5	23.1	25.4	31.8	5.7	9.4	15.9
5 – < 6	11.2	13.9	11.8	1.5	2.3	4.5
6 – < 7	3.7	4.0	2.7	0.5	0.7	0.8
7 – < 8	2.2	2.3	0.3	0.1	0.1	0.8
8 – < 9	0.6	0.6	0.2	0.0	0.1	0.6
9 – < 10	0.2	0.1	0.0	0.0	0.1	0.2
10	0.2	0.1	0.0	0.0	0.0	0.2
9+	0.4	0.3	0.0	0.0	0.1	0.4
England N	2919	2897	1072	3188	3218	1133
Winchester N	1436	1683	670	1477	1881	683
Westminster N	286	384		419	431	
England median	3.69	3.89	3.89	2.51	2.90	3.28
Winchester median	3.86	4.16	4.13	2.36	2.96	3.27
Westminster median	4.46	4.21		2.51	2.87	
England mean	3.88	3.99	3.94	2.63	2.98	3.42
Winchester mean	4.03	4.18	4.16	2.47	3.02	3.31
Westminster mean	4.53	4.52		2.58	2.96	
England Coef Var	36.23	35.32	26.44	34.94	33.80	33.96
Winchester Coef Var	35.07	31.01	24.98	33.58	32.42	23.35
Westminster Coef Var	43.59	45.35		37.25	33.71	

Source: see Table 6.

about the period 1400–49 are perforce based upon only a third the number of observations (Tables 6 and 7).

Trends over time and annual variations in the numbers of available wheat, barley, and oats yield observations are shown in Figure 16A, which differentiates between the available yield information for the Westminster estate, Winchester estate, and all other estates. In the case of Westminster, the yield data extend without a break until 1407 and then effectively cease. On this estate, although there is

no single year with full documentation for all of the abbey's demesnes, there is no year without at least some information. This contrasts with Winchester, where yield data are typically available for all demesnes or for none. The Winchester yield data constitute the single most substantial body of yield information available for any estate in the country, with three to five times as many observations in any given year as the Westminster estate. The chronological span of the Winchester data is also exceptionally long, since direct management continued until 1471.²² Leasing nevertheless began to make inroads into the number of demesnes kept in hand from the start of the fifteenth century, so there is a progressive diminution in the number of available observations from 1401 and especially 1430, while from 1456 data are restricted to the two last directly managed demesnes of Ecchinswell and Mardon. The one major weakness of the Winchester yield series is the gaps which occur whenever an enrolled pipe roll is missing.²³ Fortunately, data for a wide range of other estates bridge all these gaps and provide continuous data coverage until 1481.²⁴ Especially valuable are the yield series for Battle Abbey's Sussex demesnes of Alciston (1336–1492), Appledram (1321–89 and 1422–64), Barnhorne (1332–1493), and Lullington (1327–1466), and Glastonbury Abbey's Wiltshire demesnes of Monkton Deverill (1280–1427 and 1451–79) and Longbridge Deverill (1277–1374 and 1420–80), all of which extend into the second half of the fifteenth century and, in the case of Alciston and Barnhorne, until almost the close of that century. Of course, all of these yield series are less than complete in their chronological coverage.

Combining the data for the Westminster estate, Winchester estate, and all other estates provides 13,438 wheat, barley, and oats yield observations for the period 1349–1479, an average of one hundred and three per year (fig. 16A). For the first thirty years after the Black Death there are typically more than double this number of observations, with a maximum of two hundred and fifty-six in 1368. Numbers then remain more-or-less consistently above average until 1402. Thereafter, coverage dwindles and becomes increasingly thin from 1435 and especially 1461. Chronologies derived from these data for the fourteenth century are therefore empirically more robust than those for the fifteenth century and particularly the second half of that century. This reflects the waning and then demise of direct demesne management and its associated system of manorial

²² Campbell, 'A Unique Estate', pp. 32–33.

²³ After the Black Death yield observations are lacking for 1366*, 1380, 1397, 1404*, 1436, 1439, 1445–46*, 1450, 1455, 1457–58, 1463, 1467–68, 1470 (* denotes the end of an episcopacy and corresponding absence of either harvested information or an enrolled pipe roll).

²⁴ Campbell, *Three Centuries of English Crop Yields*.

Figure 17. English grain yield per seed and Alciston, Sussex, grain yields per seed and per acre, 1350–1479

Sources and methods: English yields from Figure 16B. Alciston yields calculated from Lewes, ESussRO, SAS/G44/1–137 (I am grateful to Anne Drewery and Christopher Whittick for transcribing these data and to the Sussex Archaeological Society for funding their work). All trends are seven-year moving averages, those for England indexed on the mean for 1300–49, those for Alciston indexed on the mean for 1336–50. For Alciston, linear regression lines are added to show trends across the period as a whole. The Alciston yields are gross of tithe and net of seed.

accounting.²⁵ Undoubtedly, there is more material awaiting discovery in the archives that might be used to amplify yet further this dataset, although it is improbable that it would do much to alter this chronological pattern.²⁶

²⁵ For a discussion of the economic incentives which promoted a switch from direct management to the leasing of demesnes, see John Munro's article in this volume, below.

²⁶ Although there are many runs of mid- to late fifteenth-century manorial accounts, few are for manors with demesnes still managed directly; nor do record office catalogues normally note whether accounts are for demesnes that were in hand or at farm. Examples of lay manors managed directly include Walterstone, Dorset (1435–50), and Mote, Sussex (1472–80). On ecclesiastical estates, direct demesne management seems to have lingered longest on Benedictine and episcopal estates in southern England, notable those of Battle Abbey, Glastonbury Abbey, Tavistock Abbey, and the bishops of Winchester. The Battle accounts are mostly preserved in The National Archives, the East Sussex Record Office, and in The Huntington Library at San Marino, California. The main collection of Glastonbury accounts is at Longleat House, Wiltshire, see Harris and Smith, *Glastonbury Abbey Records at Longleat House*. For the Tavistock material see, Finberg, *Tavistock Abbey*, and, for the Winchester material, *Winchester Pipe Rolls*, ed. by Britnell.

Table 8. Alciston, Sussex: grain yields, seeding rates, cropped acres, and real expenditure on hired labour per 100 acres (0.404 km²) cropped, 1335 to 1489

Decade	Indexed value (1360s = 100):				
	Grain yield per seed	Seed sown per grain acre	Grain yield per acre	Total acres cropped	Labour units hired per 100 acres (0.404 km ²)
1340s	139	91	147	112	
1350s	116	95	111	125	
1360s	100	100	100	100	100
1370s	133	92	123	117	89
1380s	121	86	105	140	100
1390s	114	82	96	141	89
1400s	121	80	99	124	101
1410s	120	68	83	109	129
1420s	102	68	71	109	122
1430s	113	66	77	100	129
1440s	115	71	84	94	129
1450s	105	72	77	86	131
1460s	115	75	89	84	128
1470s	97	74	74	73	159
1480s	106	73	79	79	156

Sources and methods: Yields, seeding rates, and cropped areas calculated from Alciston manorial accounts, Lewes, ESussRO, SAS/G44/1–137 (I am grateful to Anne Drewery and Christopher Whittick for transcribing these data and to the Sussex Archaeological Society for funding their work). Labour inputs are calculated from Wooldridge, 'Alciston Manor', pp. 12–13, 62–64, 73–84.

Figure 16B charts the trend of the combined grain yield per seed (indexed on the mean for 1300–49) on the Westminster estate, Winchester estate, and on all estates between 1340 and 1479.²⁷ Each aggregate chronology has been reconstructed from the component manorial chronologies using a regression method formulated by Gregory Clark. To take account of changes in geographical coverage, the national trend is the product of eight regional trends (fig. 18). The brevity of the Westminster chronology relative to the Winchester and national chronologies is immediately apparent. So, too, is the close correspondence of yield trends on the Westminster and Winchester estates from 1340 to 1400 (correlation coefficient +0.78), notwithstanding that these are based on completely independent datasets and relate to demesnes under entirely separate

²⁷ The combined grain yield has been calculated by giving equal weighting to the winter- and spring-sown grains (as also, within the spring-sown sector, to barley and oats), using the formula: $[(\text{wheat yield} \times 0.5) + (\text{barley yield} \times 0.25) + (\text{oats yield} \times 0.25)]$.

administrations, located, for the most part, in different parts of the country. Correlations between the yield series for the Winchester and the Westminster estates and that for all other estates are weaker, but still strongly positive (respectively, +0.47 and +0.61). Correlations with the national trend are the strongest (all other estates +0.72; Westminster +0.90; Winchester +0.93), although this is partly because the estate and national series are not statistically independent of each other.

All four chronologies (fig. 16B) are characterized by exceptionally depressed yields during, and in the immediate aftermath of, the Black Death. Recovery thereafter was slow although it was stronger on the Westminster and Winchester estates than in the country as a whole. In fact, on most other estates yields remained seriously depressed until the early 1370s, when yields rose strongly throughout the country to levels that at least matched and in many cases eclipsed those prevailing before the Black Death. Yields reached a peak in the mid-1380s, when they far exceeded the long-term average for the period 1340–1479. In the closing years of the fourteenth century yields fell back and remained significantly below the peak level of the 1380s for the rest of the period for which observations are available. Yields continued to sag until the 1420s, recovered slightly to a minor fifteenth-century peak in the 1450s, and then declined again to the depressed level of a hundred years earlier in the 1460s and 1470s (by which time the available data are thin and unrepresentative, fig. 16A). On this evidence, yields at the end of the fifteenth century (when agricultural resources were available in abundance) were below those achieved in the first half of the fourteenth century (when the arable area was at its maximum extent and the pressure to grow bread grains was most acute).

Because seed was invariably sown more thinly at the end of the fifteenth than the beginning of the fourteenth century, the decline in yields per acre was significantly greater than that in yields per seed.²⁸ For example, on Battle Abbey's exceptionally well-documented home farm of Alciston in east Sussex a cumulative thinning of seeding rates by one-fifth over the course of the late fourteenth and fifteenth centuries magnified a modest reduction in yields per seed into a substantial reduction in yields per acre (fig. 17 and Table 8). This progressive erosion of yields is all the more striking given that real expenditure on labour per cropped acre rose by fifty per cent, as comparatively fixed quantities of hired labour were applied to a shrinking area under tillage (Table 8).²⁹

²⁸ This is examined and illustrated in Campbell, *English Seigneurial Agriculture*, pp. 330–34.

²⁹ For a detailed discussion of labour on this demesne, see Wooldridge, 'Alciston Manor'. Cropping changed more in scale than composition over the fifteen decades spanned by the accounts: Brandon, 'Arable Farming in a Sussex Scarp-Foot Parish'.

Variations by Region and by Crop

Severely inclement weather greatly compounded by the mass mortality of managers and workers together account for the massive yield reduction which accompanied and immediately followed the Black Death.³⁰ Figure 18 demonstrates that nowhere escaped unscathed. The abrupt fall in yields was, however, more pronounced in the central and southwestern counties than those in the east and southeast, and was twice as great in Somerset and its neighbouring counties as in Kent, Surrey and Sussex. In Hampshire (north and south) and the counties of the Thames Valley the productivity crisis seems to have passed fairly quickly. In contrast, recovery was long delayed in East Anglia, the southeast, and the southwest, where yields remained depressed until well into the 1360s and did not regain their pre-Black Death level until the late 1370s.

With the exception of Sussex, the 1380s stand out as a decade of good harvests almost everywhere, especially in Essex, Hertfordshire, Middlesex, and Hampshire (north and south). The productivity recovery of these years was weakest in the southwest of England, as also in East Anglia, whose once high-yielding and labour-intensive cropping methods were in full-scale retreat by this time.³¹ Nor were these post-1375 gains in yields sustained. From the 1390s yields fell almost everywhere, and nowhere more steeply than in Wiltshire. In Essex, Hertfordshire, and Middlesex the yield decline continued into the opening decade of the new century, in East Anglia and the counties of the Thames Valley into the second decade of that century, and in the counties of the southeast and southwest into the 1420s. Only on the chalk-land demesnes of north Hampshire, whose distinctive sheep-corn husbandry was undergoing a process of expansion, did a contrary trend prevail, insofar as here yields rose to a peak in the late

³⁰ On the Winchester estate the grain harvests of 1349 and 1350 were both over a third below average and, by a significant margin, are the worst on record between 1349 and 1453; the harvests of 1351, 1352, and 1356 also stand out as seriously deficient (Farmer, 'Grain Yields on the Winchester Manors', pp. 557–58). Poor yields on the Westminster demesne of Kinsbourne, Hertfordshire, from 1349 to 1353 were the product of a combination of weather and labour supply problems (Stern, *A Hertfordshire Demesne*, ed. by Thornton, pp. 164–66, 178–79). Benedictow, *The Black Death*, nevertheless emphasizes the latter: 'Dearth and famine were a usual consequence of the Black Death (and later plague epidemics), because normal work in agriculture and urban industries tended to grind to a halt under the impact of the epidemic onslaught, with severe consequences for production and income' (p. 351). For a case analysis of the massive production shock experienced during these years within a single distinctive region, see David Stone's chapter in this volume.

³¹ Campbell, 'Agricultural Progress in Medieval England', pp. 38–39.

Figures 18A and 18B. Regional trends in English grain-yields per seed, 1340–1439: (A) eastern and southeastern England; (B) southern, south-central, and southwestern England

Sources and methods: See Figure 14. All trends are seven-year moving averages indexed on their respective means for 1300–49.

1420s.³² Thereafter, these Hampshire yields slid downwards again while those in many other counties made a modest recovery and for a time, in the southern counties of Sussex, Hampshire, Dorset, Wiltshire, and the Thames Valley, even

³² Campbell, Bartley, and Power, ‘The Demesne-Farming Systems’, pp. 163–67.

regained the average level obtaining before the Black Death. Everywhere else, however, yields remained below that standard of excellence.

Except when harsh environmental conditions limited cultivation to oats, producers always sowed a mix of grains. Wheat, rye, bere (i.e. winter barley), and various mixtures of the three were sown in the autumn, whilst spring barley, oats, and dredge (a barley / oats mixture) were sown in the spring. Beans, peas and vetches usually added further variety to the cropping mix. Each grain had differing growing requirements and met alternative consumption needs hence sowing a combination of them served to mitigate weather and market uncertainties and helped to avert the risk of outright harvest failure.³³ Only exceptionally, as in 1349 and 1350, did all three grains return seriously deficient yields.³⁴ In 1351 wheat yields were again poor, but barley and oats yields were marginally better, and then in 1352 wheat yields were good but barley and oats yields bad.³⁵ For wheat to succeed and the spring grains fail was anomalous and there would not be another instance until 1464. For wheat and even barley to do badly but oats to do well, as in 1438, 1445, 1458, 1465, 1471, and 1477, was less unusual. In fact, after 1400 yields of wheat and oats ceased to be positively correlated (1340–99 coefficient of correlation +0.33; 1400–79 coefficient of correlation -0.06), which implies that the chance of a simultaneous failure of both grains was diminishing.

For large-scale producers hoping to sell surpluses for profit, bumper harvests posed a different kind of problem, since prices slumped when markets were glutted with grain.³⁶ Years when wheat, barley, and oats all yielded abundantly were, however, rare: 1376, 1377, and 1378 stand out in this regard as the three most bountiful years of all, closely followed by 1386–88 (fig. 19). The generous yields of these years are all the more striking given the consistently poor returns that wheat and barley had delivered throughout the 1350s and 1360s (figs. 19A

³³ The main types of demesne cropping combinations are discussed in Campbell, *English Seigniorial Agriculture*, pp. 275–302.

³⁴ The years 1349 and 1350 stand out in this respect in the table entitled 'Harvest Successes, 1349–1453' in Farmer, 'Grain Yields on the Winchester Manors', pp. 557–58. At Wisbech Barton, Cambridgeshire, 'all crops yielded poorly in the aftermath of the Black Death' (Stone, *Decision-Making in Medieval Agriculture*, pp. 101–02).

³⁵ Farmer, 'Grain Yields on the Winchester Manors', p. 559, attributes this anomalous outcome to the fact that 'all available labour was used first to get in the more valuable wheat, to the detriment of other grains'. In contrast, Mate, 'Agrarian Economy after the Black Death', pp. 342–43, stresses the adverse effect upon harvests of a series of excessively dry years in the early 1350s.

³⁶ For an elucidation of the relationship between farm size, prices, and profits, see Overton, *Agricultural Revolution in England*, pp. 19–22.

Figures 19A–19C. English wheat, barley, and oats yields per seed, 1340–1479

Sources and methods: See Figure 14. All national trends are the product of eight regional sub-trends (Figure 18). Yields are indexed on their respective means for 1300–49. Sixth-order polynomials show trends across the period as a whole.

and 19B). Indeed, wheat yields had been seriously deficient in 1374 and 1375. The sudden improvement in yields from 1376 is therefore as remarkable as it must have been unexpected, the more so as, for the next twenty years, abundant yields, especially of the spring grains and above all of barley, became the norm rather than exception.³⁷ It was a phenomenon which, at least over the next ninety years, would never be repeated.

From the mid-1390s yields of wheat and barley drifted downwards again and for much of the fifteenth century were more likely to be deficient than abundant. For wheat, poor yields outnumbered good yields by five to one, and, on the scanty available evidence, yields in 1438 and 1477–78 are the worst on record (fig. 19A). In the case of barley, poor yields and good yields were more evenly matched, although most of the best yields occurred before 1460 and the bulk of the worst after 1440, with 1464 and 1473 the worst of all (fig. 19B). From 1340 to 1479, in fact, yields per seed of wheat and barley both tended to decline, with many of the most deficient yields of all occurring towards the end of this period. For oats the story is happier, with conspicuously more good than bad years and a strong tendency for yields to improve rather than deteriorate (fig. 19C). Presumably this was because oats were grown on a diminishing scale, as pottage declined as a component of diets and brewers increasingly substituted malted barley for malted oats.³⁸ Probably, too, oats gained more than wheat and barley from the shortening of rotations and withdrawal of cultivation from the poorest soils and maybe also from the amalgam of changes taking place in temperature, precipitation, and seasonality which collectively determined growing conditions. Notwithstanding these gains in oats yields, three years alone (1405, 1440, and 1455) delivered ample yields of all three main grains, a far poorer record than that of the preceding century, whose historical reputation for inferior yields is far worse.

Towards a Chronology of Post-Black Death English Grain Yields

Figure 20 summarizes these trends in grain yields, subsuming the regional variations and differences between crops discussed above. As noted above, the results for the fourteenth century are soundly based (fig. 16A). Developments during the fifteenth century are less securely documented, especially after c. 1430. In

³⁷ Unlike much early modern social unrest, 'the great revolt occurred at exactly the time when the mass of the English commons could at last look forward to an improved standard of life'; Dobson, *The Peasants' Revolt*, pp. 122–23.

³⁸ Campbell, 'Matching Supply to Demand', pp. 832–39; Galloway, 'Driven by Drink?', pp. 96–100.

Figure 20. English grain-yields per seed, 1340–1479

Sources and methods: See Figure 14. The grain yield is the wheat (barley/oats) yield, i.e. $(\text{wheat yield} \times 0.5) + (\text{barley yield} \times 0.25) + (\text{oats yield} \times 0.25)$. Yields are net of tithe and gross of seed and indexed on the mean for 1300–49. The sixth-order polynomial shows broad variations across the period as a whole. For the annual values see Appendix 1.

particular, the final decades of that century are a veritable dark age and are always likely to remain so given that direct management of seigneurial demesnes with its attendant production of annual manorial accounts had effectively ceased. Even on as conservatively managed an estate as Battle Abbey, which retained a few demesnes in hand until almost the close of the century, there are signs that the accounting process was becoming ossified with conventional rather than real figures recorded, so that the accounts themselves become less reliable.³⁹ Agricultural developments during the first hundred years after the Black Death will therefore always be clearer and more amenable to analysis than those during the second hundred years, from *c.* 1450 to *c.* 1550, when the long post-plague demographic

³⁹ At Lullington, Sussex, for example, the acreages sown and quantities seeded of each grain became conventionalized in the 1450s so that they cease to display the small changes from year to year which had hitherto been normal: Kew, TNA, SC6/1027/6–16.

malaise finally came to an end and both the population and agrarian economy at last began to expand again.⁴⁰

John Hatcher and Richard Britnell have both emphasized the episodic character of the economic history of the century and a half that followed the Black Death, and this is borne out by the chronology of yields (fig. 20).⁴¹ Six distinctive sub-periods may be distinguished. First, the disastrous harvests of 1349–51/52 which accompanied and followed the Black Death and constitute the sole example of a serious three-in-a-row yield failure on medieval record. Second, the persistently poor harvests of 1352 to 1369/1375, when recovery proved fitful and partial and yields on many demesnes remained well below their pre-Black Death level. Third, the dramatic improvement in yields from 1376 and the unprecedented and unparalleled run of bountiful harvests which then lasted until the mid-1390s. Fourth, the worsening harvests which followed and culminated in the depressed yields of the 1420s. Fifth, the heightened yield variability of the 1430s and 1440s, of which the major back-to-back harvest failures of 1437–38 and 1441–42 formed part. Sixth, following a respite in the 1450s (when, on the scanty evidence available, no serious harvest failures materialized), the return of dismal harvests in the final decades of the century, demonstrating a serious and recurrent failure of agricultural productivity more than a century after the Black Death had dramatically eased the pressure of population upon the land.

The Harvest Failures of 1349–52

Probably the single most arresting feature of this entire chronology is the profound failure of yields that accompanied the Black Death (figs 20 and 21A). That agricultural operations were badly affected by prolonged wet weather is attested by explanations and comments contained in manorial accounts.⁴² Chroniclers, too, observed that the plague was preceded and accompanied by wet

⁴⁰ For the problems of bridging this period see Clark, 'Long March of History', p. 101; Apostolides and others, 'English Agricultural Output'.

⁴¹ Hatcher, 'The Great Slump', p. 239: 'closer examination reveals that the fourteenth and fifteenth centuries experienced a succession of sub-periods each with its own distinctive characteristics'. Britnell, 'English Agricultural Output and Prices', p. 38: 'the history of output may be better told as a series of fluctuations, or phases, than as one of continuous trend'.

⁴² Autumn 1347 was wet, so, too, were winter and autumn 1348, the whole of 1349 was wet, and waterlogged soils were reported in winter and summer 1350: Titow, 'Evidence of Weather', pp. 401–03; Stern, *A Hertfordshire Demesne*, ed. by Thornton, pp. 100, 164–66.

and unseasonable weather.⁴³ Figure 13A also demonstrates that these years mark the culmination of a hundred years of global cooling. Summer temperatures in Holland were below average (fig. 21B) and extensive sea ice is recorded around Iceland in 1348–51.⁴⁴ Moreover, A. G. Dawson, K. Hickey, P. A. Mayewski, and A. Nesje have inferred from analysis of the Deuterium content of ice that in 1349–53 western Greenland experienced an episode of intense cold ‘rarely ever reached again during the later centuries of the Little Ice Age’ and colder even than the notorious 1690s.⁴⁵ These same years have been identified by Baillie as a time of depressed tree growth globally, which seems to have begun around 1342 and was at its most pronounced between 1345 and 1350 (fig. 13A).⁴⁶ Reduced levels of solar radiation are also consistent with the marked inflation in salt prices in 1350–52, with prices doubling in 1351, since much salt (both home produced and imported) was produced by evaporation (fig. 21B).⁴⁷

That English grain crops yielded badly during these years is therefore unsurprising (figs 18–21). Insofar as heavy plague mortality was a factor in depressing yields, this should have affected the oats harvest far more than the wheat, since the latter was the principal bread grain and of far greater value, whereas

⁴³ England, Chester, 1348: ‘there was inordinately heavy rain between Midsummer and Christmas, and scarcely a day went by without rain at some time in the day or night’: *The Black Death*, ed. and trans. by Horrox, p. 62 (also pp. 54, 66, 74). France, Paris, 1348: ‘for some time the seasons have not succeeded each other in the proper way. Last winter was not as cold as it should have been, with a great deal of rain: the spring windy and latterly wet, Summer was late, not as hot as it should have been, and extremely wet — the weather very changeable from day to day, and hour to hour; the air often troubled, and then still again, looking as if it was going to rain but then not doing so. Autumn too was very rainy and misty. It is because the whole year here — or most of it — was warm and wet that the air is pestilential’: *The Black Death*, ed. and trans. by Horrox, pp. 161–62.

⁴⁴ Dawson and others, ‘Greenland (GISP2) Ice Core’, p. 432.

⁴⁵ Dawson and others, ‘Greenland (GISP2) Ice Core’, p. 428.

⁴⁶ Baillie, *New Light on the Black Death*, pp. 34–39.

⁴⁷ Significantly, the single greatest inflation in salt prices on record was in 1316, at the height of the Great European Famine and following a year of incessant rain: Campbell, ‘Physical Shocks’, pp. 20–21. One reason that the price inflation was less pronounced 1350–52 than 1315–17 is because during the interim England had swung from being a net exporter to a net importer of salt, with substantial supplies sent from France’s Bourgneuf Bay, where sea salt was cheaply produced by a process of solar evaporation: Bridbury, *England and the Salt Trade*, pp. 29–30, 46–47, 50, 95, 110–11, 151–52. Significantly, in 1350–51 excessive rain ruined harvests at Chartham, Great Chart, and Ickham in Kent: Campbell, ‘Agriculture in Kent’, p. 47, n. 80. Consequently, the high prices of 1350–52 probably had at least as much to do with the weather as with the sudden plague-induced scarcity of workers.

Figures 21A–21C. English grain yields and proxy indicators of weather variations, 1340–1409

Sources and methods for Figure 21: English grain-yields per seed — from Figure 20.

English grain prices: Farmer, 'Prices and Wages', pp. 794–95; Farmer, 'Prices and Wages, 1350–1500', pp. 502–05.

Combined Wheat (Barley/Oats) price indexed on 1300–49, inverted to adjust for the normally inverse relationship between prices and harvests, and advanced one year, to correct for the lag between harvests in year x and prices in year $x + 1$ (the correlation coefficient between yields and prices lagged one year is -0.66). English salt prices: Clark, *English Prices and Wages*.

Prices are expressed as a percentage of the twenty-five-year moving average ($\times 0.2$), and advanced one year to adjust for the influence of the weather in year x upon prices in year $x + 1$ (NB production of marine salt by solar evaporation was adversely affected by cloudy and rainy summer weather).

Netherlands summer temperatures: Van Engelen, Buisman, and IJnsen, 'A Millennium of Weather'. Mean June, July, and August temperatures ($\times 2$) are indexed on the mean for 1340–1459.

Timing of the Burgundian pinot noir grape harvest: Chuine and others, *Burgundy Grape Harvest Dates*. Dates are inverted and indexed on the mean for the period 1372–1459 (i.e. the higher the value, the earlier the grape harvest and therefore the warmer the summer).

Commissions of banking and ditching (*wallis et fossatis*) concerning the tidal reaches of the River Thames (east of London Bridge): Galloway, 'Storm Flooding, Coastal Defence, and Land Use' (data kindly supplied by James Galloway) (NB commissions were normally issued *in response* to problems of flooding).

the former occupied a lesser dietary niche and could be fed either un-threshed or un-harvested to livestock.⁴⁸ Oats, thus, ought to have borne the brunt of the sudden depletion in labour supplies and inflation in labour costs. Yet this is not what happened. Wheat yields were consistently more than a third below average in 1349, 1350, and 1351, faring little better than yields of oats and, if anything, worse than yields of barley (fig. 19).⁴⁹ This implies that the harvest failure owed less to labour-supply problems than the inclement weather.

The Inferior Harvests of 1352 to 1369/1375

Unlike the situation following the earlier disastrous harvests of 1315–17, yields did not bounce back to their former level once the immediate crisis had

⁴⁸ On the Kent estate of Canterbury Cathedral Priory in 1349 the reeves at Agney and Ruckinge complained, respectively, that peas and vetches and winter barley were left unharvested because of the lack of labourers; presumably for much the same reason, livestock were fed unharvested barley at Chartham and unthreshed wheat at Mersham; the following year there were still insufficient reapers to harvest all the vetches at Mersham: Campbell, 'Agriculture in Kent', p. 47, n. 79.

⁴⁹ Farmer, 'Grain Yields on the Winchester Manors', p. 557, reports mean yields of wheat, barley, and oats respectively 33.5 per cent, 28.2 per cent, and 46.2 per cent below average in the two harvest years 1349–50.

passed.⁵⁰ Instead, in large parts of the country they remained depressed and it took twenty-five years for yields of all three principal grains to regain their pre-plague levels on a majority of demesnes (figs 19 and 20). The years until 1376 have often been described as an 'Indian summer' for large-scale demesne producers, because grain prices remained high and, after the initial wage gains of the immediate plague years, nominal wage rates were slow to improve, so that arable farming remained profitable.⁵¹ Production was therefore able to continue much as before. Yet, as the close inverse correlation between yields and prices implies (fig. 21A), if grain prices were high it was because summers, and therefore harvests, during the so-called Indian summer were unfavourable.⁵² It can be no coincidence that at this time flooding appears to have become an increasing problem in the Thames estuary (fig. 21C), as wetter weather, storm surges in the North Sea and the neglect of sea defences and drainage systems exposed the region's reclaimed marshlands to heightened risks of inundation.⁵³ Temperature reconstructions demonstrate that summers in Holland continued to be cool

⁵⁰ Indexed grain yields per seed 1314–23 and 1348–57 (source: Campbell, *Three Centuries of English Crop Yields*), showing the yield bounce-back that followed the three bad harvests of 1315–17 and the absence of any equivalent recovery following the three bad harvests of 1349–51:

Year	1314	1315	1316	1317	1318	1319	1320	1321	1322	1323
Yield	100	73	62	88	106	103	104	76	101	112
Year	1348	1349	1350	1351	1352	1353	1354	1355	1356	1357
Yield	100	60	61	73	85	87	87	92	74	86

⁵¹ Bridbury, 'The Black Death', pp. 583–84; Hatcher, 'England in the Aftermath', p. 6; Britnell, 'English Agricultural Output and Prices', pp. 21–25; Stone, *Decision-Making in Medieval Agriculture*, pp. 81–120.

⁵² Hatcher, 'England in the Aftermath', p. 8, was puzzled why 'the Black Death, and the two succeeding epidemics of 1361–62 and 1369, resulted in only modest improvements in the standards of living of labourers and artisans'. Poor harvests arising from problematic weather provide at least a partial explanation. Fungal infestation of grain crops further aggravated the situation. In Kent, mildew (first recorded as having attacked the wheat crop on the Canterbury Cathedral Priory estates at East Peckham and Meopham in 1336–37) became an endemic problem in the 1360s and 1370s and was responsible for repeated major crop failures: Campbell, 'Agriculture in Kent', p. 47. Farmer, 'Grain Yields on the Winchester Manors', p. 561, nevertheless suggests that 'the yield figures for the 1350s and possibly the early 1360s may say as much about the success of the reeves in recruiting harvesters as they do about the fertility of the arable or the kindness of the weather'.

⁵³ In 1350 the River Severn had burst its banks and caused extensive flooding on the Lordship of Berkeley's home manor of Ham, Gloucestershire: Wells-Furby, *The Lay Estate in the Fourteenth Century*. I am grateful to Dr Wells-Furby for showing the manuscript of her monograph to me.

Figure 22. Dutch tithe receipts, 1350–1449

Sources and methods: Individual tithe series for Rijnland 1343–1415, Utrecht 1370–1454, and Maasland 1343–1454 kindly supplied by Jan Luiten van Zanden. Each series has been indexed on its value for 1400 and smoothed using an eleven-year moving average. The master Dutch series is the average of these three smoothed series. The sixth-order polynomial highlights the main temporal trends.

(fig. 21B). World tree growth also registered another major decline in the early 1360s (fig. 13A). Environmentally, therefore, these were difficult years for arable producers.⁵⁴ To compound matters, recurrent plague outbreaks in 1361, 1369, and 1375 will have disrupted markets and ensured that within the seigneurial sector managerial and manpower problems remained ongoing.⁵⁵

The Generous Harvests of 1376–95

Environmental and economic conditions changed abruptly in 1376 with the first truly generous harvest for fifty years, the first, in fact, of three.⁵⁶ Yields rose and prices fell, to the benefit of wage earners and disadvantage of those selling sur-

⁵⁴ For detailed case-studies see Mate, 'Agrarian Economy after the Black Death', pp. 341–54; Stone, *Decision-Making in Medieval Agriculture*, pp. 101–13.

⁵⁵ Hatcher, *Plague, Population, and the English Economy*, pp. 21–26.

⁵⁶ For the significance of the 1376 yield rise and price fall see Bridbury, 'The Black Death', pp. 584–85; Britnell, 'English Agricultural Output and Prices', p. 26. The sudden dramatic improvement in yields shows up clearly on the Winchester estate: Farmer, 'Grain Yields on the Winchester Manors', p. 557.

pluses on a market now glutted with grain.⁵⁷ Further abundant harvests over the next twenty years reinforced the trend towards price deflation (fig. 21A) and, as their purchasing power improved, so the expectations of wage earners rose.⁵⁸ These improved yields (not only were they better, they were also more reliable) had little to do with the enterprise and ingenuity of medieval husbandmen and a great deal to do with the weather.⁵⁹ In Holland grain tithe receipts, which had been in decline since the 1350s, rose steadily from the late 1370s to the mid-1390s (fig. 22). Over this period Dutch summer temperatures also improved progressively, to a peak in the 1380s (fig. 21B). In Burgundy there was a matching shift in the timing of the grape harvest (fig. 21B), as the vines responded to the warmer temperatures and ripened earlier. In the Thames estuary the hitherto mounting flood problem suddenly abated and in the 1380s commissions for ditching and dyking sank to a minimum (fig. 21C). A marked change in North Atlantic sea-surface temperatures also seems to have set in from c. 1378–80. 'Before this time, episodes of cold water development were frequent and, in relative terms, long lasting. After this time, excursions of cold water were relatively rare and short-lived'.⁶⁰ Global temperatures actually improved during these final decades of the fourteenth century and the dendrochronological record shows that trees across the World responded with increased growth (fig. 13A).⁶¹ The worst of the great national plague epidemics had also passed.

Given that these happy environmental circumstances coincided with Chaucer's composition of *The Canterbury Tales*, this benign climatic episode may be dubbed the 'Chaucerian Anomaly'.⁶² Contrary to Malthusian logic, however,

⁵⁷ 'In the mid-1370s [...] the era of expensive grain came to a sudden end, and prices tumbled. The slump in grain prices at a time when population may well have been continuing on a downward path finally undermined the value of land', Hatcher, 'England in the Aftermath', p. 34.

⁵⁸ Clark, 'Long March of History', pp. 116–17, 133–34.

⁵⁹ In east Norfolk, for example, all the key innovations of its intensive mixed-farming regime had been made in the era of high farming well before the Black Death, and in the final decades of the fourteenth century lords were actually reducing the intensity of their husbandry: Campbell, 'Agricultural Progress in Medieval England', pp. 26–46. The annual variability of grain yields effectively halved between 1345 (coefficient of variation 1332–57 = 31.4) and 1382 (coefficient of variation 1369–94 = 16.3); the latter represents the single lowest point between 1275 and 1474: Campbell, 'Physical Shocks', p. 18.

⁶⁰ Dawson and others, 'Greenland (GISP2) Ice Core', p. 428.

⁶¹ The strong positive growth signal is apparent in the chronologies of both Old World and New World trees until the mid-1380s (coefficient of correlation 1350–86 +0.68): Baillie, *New Light on the Black Death*, pp. 36–38.

⁶² Geoffrey Chaucer (c. 1342–1400) is thought to have written *The Canterbury Tales* bet-

the population did not respond to the good harvests, abundant and cheap food, favourable real wage rates, and plentiful supply of holdings with a long-delayed surge of growth. Although ostensibly everything was propitious for a full-scale recovery of population, no such recovery was forthcoming.⁶³ Instead, all the available demographic indicators imply that the population continued to contract throughout this final quarter of the fourteenth century, for reasons about which there has been much speculation but for which there is frustratingly little direct evidence.⁶⁴ Conceivably, the post-Black Death institutionalization of servanthood had shifted marriage later, especially for women, and thereby depressed fertility. Perhaps, too, improved prospects for acquiring a land holding and a growing desire to pass holdings on intact to the next generation were privileging later (economic) over earlier (biological) marriage.⁶⁵ Imbalanced sex ratios arising from heightened local and regional migration may have reinforced this trend.⁶⁶ Almost certainly, as exemplified by the Worcestershire manor of Halesowen, recurrent plagues had transformed the age structure of the population, reducing the proportion of females within the reproductive age group and thereby depressing nuptiality.⁶⁷ More critically, it has long been speculated that background mortality, particularly of infants and children, remained high, shortening life expectancy at birth.⁶⁸ Significantly, with the fleeting exception of the quinquennium 1386–90, the replacement rate of male tenants-in-chief of the Crown (the most materially advantaged socio-economic group) remained stubbornly below unity until the late 1440s and much the same applied to several other demographic groups which have been similarly reconstituted.⁶⁹

ween 1386 and 1400. Note that the adverse weather event responsible for the Great European Famine of 1315–21 has been termed the ‘Dantean Anomaly’ (after the Italian poet Dante Alighieri, c. 1265–1321) by Brown, *History and Climate Change*, pp. 251–54.

⁶³ This contrasts with developments in Holland, where, notwithstanding the ecological disaster of rising water-table levels, the post-Black Death period witnessed significant population growth: Van Bavel and Van Zanden, ‘The Jump-Start of the Holland Economy’, pp. 505–07.

⁶⁴ For clear evidence of the downward trend in population, see: Raftis, ‘Changes in an English Village’; Poos, ‘The Rural Population of Essex’; Razi, *Life, Marriage and Death in a Medieval Parish*, pp. 114–17.

⁶⁵ For a sceptical review of the case in favour of fertility decline, see Bailey, ‘Demographic Decline’.

⁶⁶ Razi, *Life, Marriage and Death in a Medieval Parish*, pp. 117–24.

⁶⁷ Razi, *Life, Marriage and Death in a Medieval Parish*, pp. 131–35, 150–51.

⁶⁸ Hatcher, *Plague, Population, and the English Economy*, pp. 57–61.

⁶⁹ Hollingsworth, *Historical Demography*, pp. 378–79; Thrupp, ‘The Problem of Replacement Rates’; Thrupp, *The Merchant Class of Medieval London*, pp. 191–206.

The Worsening Harvests of the Early Fifteenth Century

All good things come to an end, and in the closing years of the fourteenth century yields started to deteriorate once more, sinking to a level in the 1420s almost fifteen per cent below that of the 1380s (fig. 20). Economic conditions were hardly propitious for grain producers: demand was slack, prices were low, labour was scarce, and, since the revolt of 1381, workers had become increasingly indolent and truculent.⁷⁰ Making direct demesne management pay, especially in competition with smaller producers with lower overheads, was therefore becoming an exercise in cost cutting. Many landlords now found leasing a more attractive alternative proposition since it was far less trouble and guaranteed a more assured annual income.⁷¹ Direct management consequently became the exception rather than the rule and increasingly confined to home farms charged with the direct provisioning of substantial seigneurial households.

Meanwhile, growing conditions were also deteriorating. From the close of the fourteenth century the process of global cooling resumed as the transition to the Little Ice Age gathered momentum (fig. 13A). On the continent, the opening decade of the new century witnessed a run of cool summers, as dismal as those of the 1360s, and proved to be an augury of worse to come (fig. 21B). Dutch tithe receipts resumed their decline and shrank by two-thirds over the next thirty years to reach a new low point in the mid-1420s (fig. 22). In England during this opening quarter of the fifteenth century, although bountiful harvests may have been a thing of the past, poor harvests were at least mercifully rare: the worst were those of 1401, 1408 (the poorest of four indifferent harvests), and 1422. Such relative stability did not last. Throughout these years atmospheric pressure was falling over Iceland and building over eastern Siberia until, by the 1420s, the widening pressure gradient had initiated a profound shift in northern hemisphere circulation (fig. 13B).⁷² Henceforth climatic conditions became less stable, winters in particular became stormier, occurrences of extreme winter cold became more common, and, with some notable exceptions, summers tended to become cooler (fig. 23C).

⁷⁰ Rigby, *English Society in the Later Middle Ages*, pp. 124–27; Stone, *Decision-Making in Medieval Agriculture*, pp. 121–55. Workers' attitudes were the subject of much adverse contemporary comment, Hatcher, 'England in the Aftermath', pp. 11–12.

⁷¹ Campbell, *English Seigneurial Agriculture*, pp. 59–60, 234–35.

⁷² Meeker and Mayewski, 'A 1400-Year High-Resolution Record'; Dugmore, Keller, and McGovern, 'Norse Greenland Settlement', pp. 26–29.

Figures 23A–23C. English grain yields and proxy indicators of weather variations, 1410–59

Sources and methods: English grain-yields per seed — from Figure 20. Durham tithe receipts: Dodds, *Peasants and Production* (data kindly supplied by Ben Dodds). Annual deflated cash tithe receipts are expressed as a percentage of their twenty-five year moving average. These percentages have then been indexed and averaged with the indexed grain yields to produce the combined index of grain yields and Durham tithe receipts. English grain prices, English salt prices, Netherlands summer temperatures, Timing of the Burgundian pinot noir grape harvest: see Figure 21.

The Harvest Failures of the Mid-Fifteenth Century

From the mid-1420s the heightened year-on-year variability of grain yields shows that uncertainty for arable producers was increasing (in the northeast of England the record of Durham Cathedral Priory's tithe receipts tells much the same story) (fig. 23A).⁷³ In 1428 the grain yield was the worst since 1356, yields were poor again in 1432, and then in 1437 and 1438 yields failed for two consecutive years, precipitating the single greatest harvest crisis and grain-price inflation of the fifteenth century (figs 20 and 23B).⁷⁴ The back-to-back shortfall was almost comparable in magnitude to that of 1315–16 and the lowered temperatures which prevailed over northwestern Europe from 1435 to 1438 very likely arose from a similarly powerful environmental forcing agent (intriguingly, in neither case is this likely to have been volcanic, since there are no corresponding sulphate spikes in the GISP2 Greenland ice cores).⁷⁵ Winters in these years, at least in the Netherlands, were unusually cold and summers were late and cool, delaying the grape harvest in Burgundy (fig. 23C).⁷⁶ On the Winchester estate sheep farming was adversely affected by the harsh winter conditions: expenditure on supplementary feeding increased, mortality rates soared, reproduction rates were depressed, and fleece weights are among the lowest on record.⁷⁷ Reduced levels of solar radiation are also reflected in the concurrent sharp inflation in salt prices, which implies that conditions were wet as well as cold (fig. 23C).

Nor was there any immediate and dramatic amelioration in these adverse conditions.⁷⁸ Unfavourable weather returned in 1441 and 1442, when yields at Alciston, Sussex, were worse even than those of 1437–38 and those at Walterstone, Dorset, were only marginally better.⁷⁹ It was not until the mid-1440s that this

⁷³ For the increasing difficulties experienced by demesne producers in the 1420s and 1430s, see Britnell, 'English Agricultural Output and Prices', pp. 34–35 (he characterizes the period c. 1435–65 as the 'mid-fifteenth-century slump', pp. 35–36).

⁷⁴ Hatcher, 'The Great Slump', p. 246.

⁷⁵ I am grateful to Frank Ludlow for this information. See <<http://www.gisp2.sr.unh.edu/>> [accessed 21 April 2010] for further information about the American GISP2 ice-core project.

⁷⁶ The winters of 1432–35 and 1437–38 were all well below average in the Netherlands; that of 1435 was one of the two coldest of the fifteenth century (1408 was the other), and 1437 was only marginally less severe: Van Engelen, Buisman, and IJnsen, 'A Millennium of Weather', pp. 101–24.

⁷⁷ Stephenson, 'Wool Yield in the Medieval Economy', pp. 383–84.

⁷⁸ Bridbury, *England and the Salt Trade*, pp. 152–53.

⁷⁹ Combined grain yields per seed were thirty-six and sixteen per cent below their twenty-five-year average in 1437 and 1438, compared with thirty-five per cent and thirty-six per cent

crisis had finally passed. This episode coincides with depressed temperatures and tree growth world-wide (fig. 13A).

The Depressed and Variable Harvests of the Late Fifteenth Century

From the 1450s the available yield data become increasingly sparse and unrepresentative, although most of the demesnes that are recorded do have the merit of being served by long runs of surviving accounts. Battle Abbey's home farm of Alciston in East Sussex is the best documented of them, and here yields continued to fluctuate around the level at which they had settled in the 1420s (fig. 17). On the same estate, at nearby Lullington and Barnhorne, yields likewise remained trend-less, if albeit marked by much annual variation.⁸⁰ On Glastonbury Abbey's twin Wiltshire demesnes of Longbridge Deverill and Monkton Deverill the variability of yields is similarly striking.⁸¹ On none of these demesnes did the third quarter of the fifteenth century bring any significant recovery or improvement of yields and on all of them it delivered some individually disastrous harvests, as bad as, and sometimes worse than, those of the immediate post-plague years. Grain yields at Alciston were seriously deficient in 1457 and 1471 and from 1475 to 1478 were consistently below their twenty-five-year average, with 1476 the worst year of the four; the harvest failed again in 1485 (fig. 17).⁸²

The 1470s were evidently an exceptionally difficult decade. Growing conditions for British Isles oaks were as variable as those for grain crops, although for the contrary reason that oaks thrived on cold winters and cool, moist summers and during the third quarter of the fifteenth century British Isles oaks put on some impressively wide rings. A range of indices imply that environmental conditions continued to present difficulties to grain producers, it is therefore tan-

below that average in 1441 and 1442: calculated from: Lewes, ESussRO, SAS/G44/73-109 (note that yields at nearby Barnhorne, Sussex, were thirty-nine per cent below average in 1441: San Marino, Hunt. Libr., HEH BA, 375-406). At Walterstone, Dorset, 1437 returned the single worst grain yield between 1435 and 1450, but yields in 1440 and 1441 were consecutively poor and only ten per cent better: Kew, TNA, SC6/833/24-36 and Kew, TNA, SC6/834/1-3. In contrast, whereas yields at Longbridge Deverill in 1441 were indifferent, those in 1437 had been poor and those in 1438 disastrous: Longleat Hse, GA, 9821-30.

⁸⁰ Lullington: Kew, TNA, SC6/1027/1-15. Barnhorne: San Marino, Hunt. Libr., HEH BA, 393-430.

⁸¹ Longbridge Deverill and Monkton Deverill: Longleat Hse, GA, 9837-9961 and 9715-9804.

⁸² Lewes, ESussRO, SAS/G44/102-37.

talizing that during the final quarter of the fifteenth century direct evidence of English crop yields finally peters out (fig. 16A).⁸³ It is also all the more intriguing that a century later, when annual yield data (derived from probate valuations) next become available, yields were clearly rising, notwithstanding that the adverse weather conditions associated with the Little Ice Age were approaching their most extreme.⁸⁴ Evidently, adverse weather conditions were not an insuperable obstacle to improved grain yields provided these were offset by powerful economic incentives to intensify, invest, improve, innovate, and specialize.⁸⁵ For English grain producers one of the key differences between the fifteenth and sixteenth centuries was that demand was slack and dispersed during the former and expanding and increasingly concentrated during the latter.⁸⁶ The growth of London, in particular, provided a powerful stimulus to farmers within a rapidly expanding hinterland to raise output and productivity.⁸⁷ In this scenario the challenge to historians is to establish exactly when and why stagnation gave way to recovery and growth.⁸⁸

Causes and Effects of Variations in Grain Yields

Following the Black Death, as Farmer correctly diagnosed, reductions in the cultivated area, higher stocking densities, improved rotations, enlarged sowings of legumes, thinner seeding rates, and stricter accounting and auditing failed to translate into any immediate, significant, or sustained rise in yield ratios. Only oats, the

⁸³ For evidence of heightened health hazards for humans at this time, see Richard M. Smith, 'Measuring Mortality in an Age of Plague: England, 1349–1540', this volume.

⁸⁴ Apostolides and others, 'English Agricultural Output'.

⁸⁵ Poor yields were nevertheless responsible for the return of near-famine conditions in 1555–56 and 1594–97: Campbell, 'Four Famines and a Pestilence', pp. 42–47.

⁸⁶ The national population shrank by a quarter between 1377 and 1450 and then more than doubled between 1450 and 1600; over the latter period London's population more than quadrupled to reach c. 200,000: Broadberry, Campbell, and van Leeuwen, 'English Medieval Population'; De Vries, *European Urbanization*, p. 270. Between 1377 and 1524 the urban share of the population may have been static or declining: Rigby, 'Urban Population in Late Medieval England'.

⁸⁷ Before 1500 London grew in importance but not in size: Keene, 'Changes in London's Economic Hinterland'. Thereafter, it grew in both size and importance: Wrigley, 'A Simple Model of London's Importance'. For the link between urban growth and agricultural improvement see, Allen, 'English and Welsh Agriculture'.

⁸⁸ Broadberry, Campbell, and van Leeuwen, 'English Medieval Population'; Apostolides and others, 'English Agricultural Output'.

hadiest of grains but sown in diminishing quantities, showed an improvement in yield, but this was offset by a deterioration in the yield of the premier bread grain, wheat.⁸⁹ Collectively, grain yields per seed were marginally lower at the end of the fifteenth than they had been at the beginning of the fourteenth century. Because of thinner seeding rates, yields per sown acre were certainly lower at the end than the beginning of this period. With less intensive rotations and more frequent fallowing, yields per unit area of arable were probably lower still.⁹⁰ When grain yields eventually started to improve sometime in the sixteenth century they first had to recover to the levels attained before the Black Death when late medieval arable farming had been at fullest stretch.⁹¹

How is this lack of any post-Black Death yield dividend to be explained? It is tempting to presume that reduced labour inputs per unit area provide the key. Certainly, the Black Death and its subsequent outbreaks ministered a massive demographic shock, halving the available workforce within the space of thirty years and initiating the single greatest inflation in the wage rates of building workers and farm labourers in recorded English wage history.⁹² Confronted by a doubling in the cost of undertaking the most labour-intensive agricultural tasks (manuring, marling, weeding, multiple ploughings), demesne managers had little option but to curtail or abandon these practices.⁹³ Nor was customary labour a practical substitute for increasingly expensive waged labour, since plague mortality had thinned the ranks of villein tenants and those who survived strove to negotiate lower rents and liberate themselves from servile obligations. Works once performed conscientiously were now discharged grudgingly or not at all; many simply lapsed.⁹⁴ Inputs per demesne acre of servile labour therefore probably shrank even more than those of waged labour and by the fifteenth century

⁸⁹ Nationally, oats shrank from thirty-nine per cent of the cropped area in 1300, to thirty-two per cent in 1420, to twenty per cent in 1600: Apostolides and others, 'English Agricultural Output'.

⁹⁰ Campbell, *English Seigniorial Agriculture*, pp. 374–85.

⁹¹ Campbell and Overton, 'A New Perspective', pp. 66–76.

⁹² Campbell, 'Nature as Historical Protagonist', pp. 285–87; Phelps Brown and Hopkins, *A Perspective of Wages and Prices*, pp. 28–31, 44–58; Clark, 'Long March of History', pp. 130–34.

⁹³ On the bishop of Winchester's demesne at Rimpton, Somerset, twenty-two per cent less labour per sown acre was expended between 1350 and 1403 than between 1275 and 1324: Campbell, *English Seigniorial Agriculture*, p. 383. On the prior of Norwich's demesne at Martham, Norfolk, labour inputs per *arable* acre were at least thirty per cent lower at the beginning of the fifteenth as the beginning of the fourteenth century: Campbell, 'Agricultural Progress in Medieval England', pp. 38–39.

⁹⁴ Stone, 'Productivity of Hired and Customary Labour'.

had dwindled to insignificance.⁹⁵ Under these employment circumstances it is perhaps unsurprising that in the long-term yields tended to sag.

In once populous and intensively cropped East Anglia and the southeast, reduced labour inputs per unit area probably help explain why the post-Black Death decline in yields was so prolonged and the eventual recovery of yields weaker than in most other parts of the country (fig. 18A).⁹⁶ The traditional fabric of cultivation nevertheless held up remarkably well during the decades immediately following the Black Death. Instead, it was during the final decades of the fourteenth century (in the aftermath of the Peasants' Revolt, when residual labour services were being repudiated, the Statute of Labourers proved least enforceable, wage rates were rising strongly, and grain prices were depressed) that demesne managers made the most vigorous economies in the deployment of labour. Paradoxically, however, yields at this time rose rather than fell (fig. 18A), which implies that labour inputs are at best an incomplete explanation of trends in yields during the half-century that followed the Black Death. In fact, on Battle Abbey's home demesne of Alciston in east Sussex labour inputs appear to have had little bearing upon the long-term tendency for yields to decline (fig. 17 and Table 8): during the fifty-year interval from the 1370s to 1420s yields per acre fell by over forty per cent and the cropped area contracted by seven per cent, but in real terms the amount of labour hired per cropped acre rose by at least thirty per cent. On this demesne the monks did their best to maintain the demesne workforce and hold labour inputs steady, so much so that the progressive reduction of the area under crop effectively raised real labour inputs per unit area. Yet even this failed to arrest the relentless downward slide of yields.

Part of the problem at Alciston, as elsewhere, may have been that demesne managers typically sowed seed taken from the previous year's crop or transferred from elsewhere on the estate.⁹⁷ In the very long term, this probably resulted in a progressive depletion of the botanical quality of seed stocks, in terms of their resistance to disease, resilience to the weather, and capacity to reproduce. Such a hypothesis is certainly consistent with the long-term tendency for yields of wheat, the most valuable and widely traded of the grains, to diminish. Reversing this trend may therefore have been contingent upon emergence of a greater awareness of the critical importance of seed quality and, thus, the merits of systematic seed selection, exchange and importation of seeds, and the commercialization of seed

⁹⁵ As, for example, on the Westminster demesne of Kinsbourne: Stern, *A Hertfordshire Demesne*, ed. by Thornton, pp. 184–89.

⁹⁶ Campbell, 'Agricultural Progress in Medieval England', pp. 38–39.

⁹⁷ Campbell, *English Seigniorial Agriculture*, pp. 189–90, 414–15.

production and supply.⁹⁸ Economic conditions prevailing in land-abundant post-Black Death England, with its limited pockets of concentrated urban demand, were, however, hardly conducive to such developments, hence the continued reliance upon on-the-farm sources of seed with all their inherent and cumulative botanical limitations.

Although grain yields may have been essentially flat in the long-term, they were far from unvarying in the short and medium terms. Of particular interest are those variations replicated to some degree or other across the whole or greater part of the demesne sector, irrespective of estate or region, since they reflect the influence of over-arching factors. Few agencies had greater influence upon yields than the weather; of all the key agricultural inputs, it was the one over which producers had least control.⁹⁹ Nor, as has been demonstrated (figs 13, 21, and 23), was the weather stable during the century and a half that followed the Black Death. The first wave of plague itself coincided with the culmination of a prolonged secular decline in global temperatures which impacted negatively upon world tree growth (fig. 13A). Although the respective contributions of inclement weather and heavy plague mortality to the disastrous harvest of 1349 remain to be established, it seems certain that the ensuing bad harvests of 1350 and 1351 were both largely weather related since there is clear environmental evidence that these years were climatically anomalous.¹⁰⁰ Cooler, wetter, and stormier conditions persisted for the next twenty to twenty-five years and inhibited yields from recovering to their pre-Black Death average (figs 21B and 21C).

Conditions changed suddenly and dramatically in 1376 with the onset of a twenty-year growth bonanza: the 'Chaucerian Anomaly'. This coincided with significant increases in global temperatures and world tree growth (fig. 13A).¹⁰¹ Sustained episodes of cold sea-surface temperatures in the North Atlantic also came to an end.¹⁰² This reversion to benign environmental conditions nevertheless

⁹⁸ Buttress and Dennis, 'The Early History of Cereal Seed'; Allen, *Enclosure and the Yeoman*, pp. 206–07; Olmstead and Rhode, 'The Red Queen'.

⁹⁹ For a pioneering discussion of the relationships between weather and agricultural productivity, see Stern, *A Hertfordshire Domesne*, ed. by Thornton, pp. 21–37, 77–103.

¹⁰⁰ Baillie, *New Light on the Black Death*, pp. 197–98; Campbell, 'Physical Shocks', pp. 20–24.

¹⁰¹ The upturn in tree growth is apparent in both hemispheres and is especially pronounced in the records of European and British Isles oaks: Baillie, *New Light on the Black Death*, pp. 27–39. In Britain, weather that was good for oak growth was normally unfavourable for crop yields, but during the final quarter of the fourteenth century oaks grew vigorously and grain crops yielded heavily, which suggests that environmentally there was something quite unusual about this period.

¹⁰² Dawson and others, 'Greenland (GISP2) Ice Core', p. 429.

proved transitory. With the dawn of the new century growing conditions gradually deteriorated once more. Global cooling resumed and from the 1420s grain producers had to adapt to significantly less favourable and predictable weather conditions as atmospheric pressure gradients and circulation patterns shifted across the northern hemisphere (fig. 13B). In the second quarter of the fifteenth century bad harvests occurred with increasing frequency, climaxing with the back-to-back failure of 1437–38 (figs 20 and 23). Once again, prolonged cool, wet weather had spelled disaster for English grain producers, and the unfavourable weather continued into the early 1440s. The next decades brought some respite, insofar as yields apparently held up reasonably well. In the 1470s and 1480s, however, some of the individual harvests reported on those few southern English demesnes that remained in hand are the worst on record. Tantalizingly brittle as are the available yield data in this, the twilight of direct demesne management, they do hint at the possibility that weather-induced harvest failure was on the increase.

These weather-related developments are of interest in themselves and for the insight they provide into the major climatic transition taking place over these years, but they also shed fresh light upon several intriguing aspects of this enigmatic economic period. Note, in particular, the coincidence of plague and serious harvest failure in 1349–51 and the association of both with extreme weather.¹⁰³ This conjuncture of plague, adverse weather, and poor yields also raises fundamental and as yet little explored questions about the immediate direct and indirect impacts of plague mortality upon agricultural output and productivity.¹⁰⁴ Note, too, that the high grain prices which underpinned the ensuing so-called Indian summer of direct demesne production may have owed more to the depressive effect upon yields of the continuing poor weather than a mortality-induced inflationary increase in coin supply *per capita*.¹⁰⁵ Prices were high first and foremost because harvests were deficient and it was dear food which

¹⁰³ Campbell, 'Physical Shocks', pp. 20–24.

¹⁰⁴ The pioneering study of this issue is Levett, *The Black Death on the Estates of the See of Winchester*. For a recent review of the evidence see Braid, 'Economic Behavior, Markets and Crises', pp. 351–58.

¹⁰⁵ Farmer, 'Prices and Wages, 1350–1500', p. 441: 'the money supply increased both absolutely and *per capita* in the 1350s and 1360s. This was probably the principal reason for the continued high prices of the two decades after the Black Death'. Likewise, Britnell, 'English Agricultural Output and Prices', p. 24; Braid, 'Economic Behavior, Markets and Crises', pp. 356–57, 370–72. Munro, 'Money, Prices, and Wages in Fourteenth-Century England', pp. 348–49, notes that prices rose in Flanders as well as England and remained high for a generation following the Black Death.

underpinned the contemporary rise in the in the prices of other commodities.¹⁰⁶ These same poor yields and high food and commodity prices obstructed workers from making further significant gains in real wages for an entire generation after the Black Death.¹⁰⁷ True, the Statute of Labourers may have succeeded in placing some restraint upon wage increases, but the continuing high food prices were at least as great a brake upon purchasing power (although they will have raised the monetary value of food liveries which, of course, lay outside the purview of the Statute of Labourers).¹⁰⁸

The sudden improvement in yields that set in from 1376 was literally heaven sent, insofar as it sprang from transformed environmental conditions.¹⁰⁹ Bumper yields replaced scarcity with plenty, driving down prices to the benefit of consumers. Those employing waged labour to produce surpluses for sale found themselves squeezed hard, whereas workers experienced rising expectations.¹¹⁰ From this dichotomy sprang many of the social tensions that found violent expression in the Peasants' Revolt of June 1381.¹¹¹ Judged by yields alone, the thirty years from 1376 constituted a quite exceptionally successful agricultural episode, but these high yields, at a time of dwindling and weakening demand, created a crisis of over-production for large-scale arable producers which is why — viewed from their perspective — it is more usually regarded as a period of agricultural difficulty and recession.¹¹² Estate officials responded by diversifying

¹⁰⁶ Correlation coefficients for the yield per seed of wheat (the principal price maker) and price of wheat (advanced one year) are consistently strongly negative: 1275–1324, -0.71; 1300–49, -0.67; 1325–74, -0.66; 1350–99, -0.77; 1375–1424, -0.73; 1400–49, -0.69. The lack of any substantial or significant drop in the strength of the correlation across the watershed period 1325–74 is striking (note: the equivalent correlation for the one hundred-year period 1300–99 is -0.71). The implication is clear; between 1275 and 1449 variations in yields account for the bulk of all variation in grain prices.

¹⁰⁷ Hatcher, 'England in the Aftermath', p. 24: 'the extraordinarily sluggish behaviour of the real wage statistics which have been computed for the quarter-century after the Black Death is also due in major part to the high price of basic foodstuffs'. Also, Clark, 'Long March of History', p. 133; Munro, 'Revisions'; Munro, 'Money, Prices, and Wages in Fourteenth-Century England', pp. 348–57.

¹⁰⁸ The limited effect of the Statute upon wages in cash and, particularly, upon payments in kind is discussed in Hatcher, 'England in the Aftermath', pp. 20–23.

¹⁰⁹ Those who advance monetary factors as the primary cause of the post-Black Death price rise are more cautious in employing such factors to account for the timing and scale of the post-1376 price fall, Munro, 'Money, Prices, and Wages in Fourteenth-Century England', pp. 357–58.

¹¹⁰ Overton, *Agricultural Revolution in England*, pp. 19–22.

¹¹¹ Dobson, *The Peasants' Revolt*, pp. xix–xlv.

¹¹² Britnell, 'English Agricultural Output and Prices', p. 26: 'the movement of prices and

into livestock, scaling down their arable enterprise, or farming out their lands piecemeal or wholesale to tenants. A full-scale Malthusian recovery of population might have retrieved the economic situation for large-scale producers but was not forthcoming. In its absence, demand continued to wither and the crisis for demesne managers to deepen.

From the final decades of the fourteenth century, therefore, arable production settled into a low-level equilibrium characterized by relatively extensive methods of production which delivered modest levels of land productivity that were always more prone to fall than rise. Even in the land-rich fifteenth century, with its favourable ratio of grassland to arable and generous wage rates, serious harvest failure remained a real hazard and the occasional major back-to-back failure, as in 1437–38, could still bring the most vulnerable members of society to the brink of famine.¹¹³ London responded to that crisis by establishing its first public granary.¹¹⁴ More generally, the experience of these hard years and others which followed as the fifteenth century drew to a close served to heighten concern about poverty, vagrancy and public order and spur contemporary quests for improved social security and welfare, through the formation of guilds, fraternities, foundation of almshouses and charities, and institution of voluntary parish relief schemes.¹¹⁵ Many of the most abiding economic and social features of the long years of demographic decline and stagnation that followed the Black Death therefore sprang in part from the low, varying and uncertain yield of grain.¹¹⁶

wages from the mid-1370s compels us to consider the period 1376–89 as one of widespread agrarian recession.’

¹¹³ Campbell, ‘Four Famines and a Pestilence’, pp. 42–46.

¹¹⁴ Campbell and others, *A Medieval Capital*, p. 104.

¹¹⁵ Dyer, *Making a Living*, pp. 312, 355; Dyer, *An Age of Transition*, pp. 238–40; Holt, *Robin Hood*, pp. 195–96.

¹¹⁶ This essay is dedicated to John Hatcher with gratitude and admiration. Research for it was undertaken with support from the UK’s Economic and Social Research Council (Award RES-000–23–0645), British Academy, Sussex Archaeological Society, and Leverhulme Trust. Anne Drewery, Marilyn Livingstone, and Christopher Whittick assisted with data collection, Elaine Yeates and the staff of the Centre for Data Digitisation and Analysis, The Queen’s University of Belfast, with data inputting, and Bas van Leeuwen with data analysis. Ben Dodds and Jan Luiten van Zanden contributed tithe data. Mike Baillie gave advice and supplied data on dendrochronology. Gregory Clark gave statistical help and advice on the construction of time series. The figures were drawn by Gill Alexander. The text was much improved as a result of comments made by Mark Bailey and Steve Rigby. Any errors remain my own.

Appendix 1

Yields Per Seed (YPS) Net of Tithes and Gross of Seed on the Westminster Estate, Winchester Estate, and in England as a Whole, Indexed on their Respective Means for 1300–49

End year	Westminster		Winchester		England		Wheat	Barley	Oats
	No.	W(B/O) YPS	No.	W(B/O) YPS	No.	W(B/O) YPS	YPS	YPS	YPS
1	2	3	4	5	6	7	8	9	10
1300	27	85	102	92	208	94	91	93	101
1301	33	99	111	105	228	102	105	101	97
1302	36	77	108	100	223	97	98	95	97
1303	33	106	0		124	107	113	111	89
1304	36	65	0		130	86	83	86	92
1305	30	77	77	91	221	91	102	76	83
1306	24	72	103	93	206	93	101	84	85
1307	26	99	96	96	217	99	100	100	94
1308	25	93	99	114	204	101	96	102	112
1309	22	94	107	112	204	104	110	104	92
1310	19	93	106	90	182	99	93	111	100
1311	18	125	108	119	202	110	118	106	97
1312	22	112	104	108	214	104	111	111	84
1313	25	93	110	116	201	103	112	102	86
1314	19	108	104	104	177	101	107	99	94
1315	16	60	100	59	181	74	63	82	87
1316	5	61	94	39	161	63	50	74	77
1317	10	97	95	74	160	89	96	83	82
1318	11	90	100	126	203	107	121	95	90
1318	29	120	0		105	104	96	110	113
1320	23	112	91	106	225	106	100	106	116
1321	27	60	0		67	77	75	82	76
1322	30	113	0		90	102	95	110	108
1323	34	109	0		102	113	104	123	120
1324	38	83	91	101	225	99	94	103	105
1325	20	94	104	131	215	108	115	95	108
1326	15	189	108	131	218	117	123	119	102

End year	Westminster		Winchester		England		Wheat YPS	Barley YPS	Oats YPS
	No.	W(B/O) YPS	No.	W(B/O) YPS	No.	W(B/O) YPS			
1327	21	128	109	118	225	105	102	98	117
1328	24	75	101	96	181	91	89	85	102
1329	14	88	101	112	195	103	103	101	104
1330	25	140	94	98	201	105	108	102	104
1331	20	56	95	101	199	90	90	78	100
1332	10	107	88	113	169	107	112	98	107
1333	5	143	0		110	131	143	124	115
1334	8	96	0		84	110	115	100	112
1335	26	104	99	102	206	101	101	95	108
1336	7	95	104	107	198	105	103	101	115
1337	17	124	103	130	200	114	120	113	105
1338	23	122	106	135	220	121	120	124	122
1339	23	82	106	60	202	83	61	117	92
1340	15	108	103	99	203	106	111	107	96
1341	33	107	105	85	209	99	91	106	108
1342	14	119	106	116	192	113	111	110	119
1343	13	126	109	86	202	100	92	111	106
1344	17	132	109	130	206	118	122	119	110
1345	29	121	105	85	188	99	107	106	77
1346	38	76	104	78	222	87	78	92	100
1347	20	113	110	95	218	100	89	106	118
1348	32	129	103	105	196	106	98	110	119
1349	24	27	103	41	194	64	60	66	69
1350	23	49	127	50	233	65	66	66	62
1351	24	79	125	63	209	77	64	83	98
1352	25	80	130	94	223	90	122	56	62
1353	21	99	128	96	240	92	92	81	102
1354	18	94	74	106	165	93	90	88	103
1355	18	114	115	101	201	98	93	97	108
1356	18	55	130	75	205	78	88	59	76
1357	19	88	127	91	199	91	89	83	102
1358	16	109	107	114	177	97	94	87	112
1359	11	125	98	96	174	93	87	96	103

End year	Westminster		Winchester		England		Wheat YPS	Barley YPS	Oats YPS
	No.	W(B/O) YPS	No.	W(B/O) YPS	No.	W(B/O) YPS			
1360	13	99	105	107	173	93	93	85	102
1361	11	99	127	100	190	92	102	76	87
1362	21	98	125	80	207	85	73	71	121
1363	21	80	116	89	222	88	72	91	118
1364	25	111	124	107	233	99	94	103	108
1365	22	104	126	115	223	96	91	91	111
1366	23	128	0		94	103	106	95	106
1367	24	82	92	74	209	81	69	81	104
1368	25	80	129	100	256	91	91	83	100
1369	26	80	113	84	221	82	71	80	107
1370	27	117	120	118	213	106	95	110	122
1371	33	133	137	117	255	105	92	114	124
1372	32	99	130	105	251	95	82	104	112
1373	29	148	126	148	242	121	107	135	136
1374	28	108	122	94	197	88	74	92	112
1375	28	84	110	98	198	88	76	96	106
1376	31	138	121	137	217	117	112	118	125
1377	31	155	126	137	235	120	110	121	138
1378	30	124	129	146	218	121	115	132	122
1379	32	95	126	106	221	99	82	111	122
1380	36	104	1		84	104	92	118	112
1381	29	135	96	127	189	109	92	116	137
1382	36	131	122	126	208	112	96	122	132
1383	29	109	91	136	185	110	102	100	135
1384	23	163	100	133	184	119	120	122	116
1385	25	108	108	123	182	104	96	96	125
1386	24	146	85	139	165	117	105	113	144
1387	24	158	101	147	169	123	113	123	141
1388	21	126	121	152	194	119	110	120	135
1389	24	110	90	114	159	104	94	109	118
1390	23	75	87	95	157	91	81	97	107
1391	15	128	3	135	43	118	115	108	133
1392	22	165	25	124	109	119	117	118	125

End year	Westminster		Winchester		England		Wheat YPS	Barley YPS	Oats YPS
	No.	W(B/O) YPS	No.	W(B/O) YPS	No.	W(B/O) YPS			
1393	27	91	99	128	169	106	98	103	125
1394	19	127	114	123	186	107	111	90	116
1395	33	122	114	117	189	106	96	108	125
1396	29	107	111	95	181	96	81	105	116
1397	30	87	0		55	96	106	76	96
1398	30	133	31	102	110	108	105	98	124
1399	20	103	89	114	144	101	93	100	119
1400	15	97	104	109	166	98	84	102	123
1401	17	90	100	84	154	88	67	99	117
1402	9	98	95	109	150	104	89	103	136
1403	12	99	6	107	47	105	92	111	125
1404	6	108	0		32	108	101	106	123
1405	3	121	35	122	76	113	119	110	105
1406	3	56	65	89	106	90	74	96	119
1407			6	126	36	97	86	104	111
1408			48	96	84	88	82	86	103
1409			66	100	99	92	84	92	110
1410			63	105	90	106	92	110	127
1411			65	111	99	101	86	102	131
1412			69	125	101	108	91	118	131
1413			69	112	103	96	92	93	104
1414			84	113	122	97	95	92	107
1415			46	109	94	97	87	92	121
1416			69	98	109	91	78	83	125
1417			3	115	21	108	98	100	137
1418			49	96	78	92	78	100	112
1419			54	114	68	103	107	94	103
1420			59	95	94	90	67	98	125
1421			57	107	87	94	82	96	116
1422			60	93	102	86	92	71	88
1423			66	119	99	101	87	103	127
1424			63	108	94	91	86	73	119
1425			59	112	93	101	90	93	134

End year	Westminster		Winchester		England		Wheat YPS	Barley YPS	Oats YPS
	W(B/O)		W(B/O)		W(B/O)				
	No.	YPS	No.	YPS	No.	YPS			
1426			6	132	21	103	99	97	117
1427			43	121	72	101	92	93	125
1428			3	103	28	78	65	77	107
1429			51	105	79	96	86	93	118
1430			50	111	77	103	90	97	135
1431			45	122	62	112	98	106	148
1432			48	93	68	88	81	85	106
1433			42	102	56	107	101	83	143
1434			42	121	60	115	107	103	144
1435			38	103	66	100	88	89	135
1436			0		21	108	91	107	142
1437			3	58	21	84	70	88	107
1438			9	66	35	81	50	91	135
1439			0		24	111	91	107	154
1440			31	120	59	118	110	112	141
1441			40	111	59	98	79	92	141
1442			5	77	23	92	92	78	107
1443			6	78	27	99	78	110	130
1444			3	89	21	108	91	107	142
1445			0		18	100	77	79	169
1446			0		14	107	87	106	148
1447			25	96	43	103	84	100	144
1448			22	116	38	104	92	96	138
1449			17	90	30	95	91	83	114
1450			0		12	99	85	82	144
1451			12	101	27	106	73	116	164
1452			12	102	29	106	94	98	140
1453			9	124	22	114	95	95	169
1454			9	105	29	101	96	96	115
1455			0		15	124	117	99	163
1456			6	120	23	114	102	107	147
1457			0		22	89	77	96	106
1458			0		22	107	84	82	178

End year	Westminster		Winchester		England		Wheat YPS	Barley YPS	Oats YPS
	No.	W(B/O) YPS	No.	W(B/O) YPS	No.	W(B/O) YPS			
1459			6	106	18	116	106	113	140
1460			6	78	19	96	74	101	135
1461			6	87	21	97	81	88	136
1462			6	103	18	102	94	107	113
1463			0		15	107	114	101	98
1464			4	48	16	74	99	42	58
1465			6	101	13	101	79	86	161
1466			6	120	14	110	95	102	146
1467			0		6	102	91	93	132
1468			0		9	92	91	86	100
1469			6	85	15	101	82	101	138
1470			0		9	90	83	91	104
1471			6	80	15	90	65	89	142
1472					9	109	109	100	117
1473					9	77	81	56	89
1474					13	94	90	69	125
1475					9	107	103	84	136
1476					8	122	87	77	236
1477					5	94	59	76	183
1478					5	74	56	69	115
1479					8	97	79	120	112

Sources and methods: see the notes to Figures 13, 16, and 19.

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