Fertilization by manure: a manor model comparing English demesne and peasant land, *c.*1300*

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Abstract

If peasant land had been only as productive as demesne land at the turn of the fourteenth century, most English peasants would not have been able to make a living, since their holdings were too small. By modelling two hypothetical manors, one based on Midland conditions and one based on East Anglian conditions, this article argues that peasants' output per arable acre must have been 50 per cent higher on average. This was possible because they had much larger amounts of manure at their disposal with which to fertilize their land. The model is based on estimated stocking densities for three types of farms, namely cottages, half-virgates and demesnes, as well as live weights of cattle, sheep and pigs. The results support the view that the minimum farm size needed for subsistence was much smaller than has hitherto been held to have been necessary.

Around 1300, when English population numbers were at their medieval peak, many peasant holdings were smaller than what scholars consider necessary to support a household.[1] With reference to Kitsikopoulos' minimum farm size of 18 arable acres and 2 acres of meadow, three-quarters of the holdings in Kanzaka's Hundred Rolls analysis were below threshold size.[2] Although estimates of threshold size vary from scholar to scholar, they invariably base their estimates upon demesne yield figures.

Until recently, scholars assumed that the non-seigneurial sector was less productive than the seigneurial, since peasants had more difficulty in fertilizing their land. Postan and Titow emphasized the shortage of manure available for the arable of customary tenants as a result of the lord's right to fold the sheep of his tenants on his demesne land. In the 1960s Postan developed his influential theory of the exhaustion of the soil, arguing that, due to population pressure, many acres of pasture were converted into arable land during the thirteenth century.

* I am indebted to the Review's referees for their valuable comments.

[1] John Hatcher and Mark Bailey, *Modelling the middle ages, the history and theory of England's economic development* (2001), pp. 44–6.

[2] Harry Kitsikopoulos, 'Standards of living and capital formation in pre-plague England: a peasant budget model', *EcHR* 53 (2000), pp. 248–50; Junichi Kanzaka, 'Villein rents in thirteenth-century England: an analysis of the Hundred Rolls of 1279–1280', *EcHR* 55 (2002), p. 599.

Since pastures supplied the grass necessary to support livestock, shortage of pasture land in many English regions led to a shortage of livestock, i.e. low numbers of horses, cattle, swine and sheep. In turn shortage of livestock led to shortage of manure. Shortage of manure led to exhaustion of the soil, because manure was essential to fertilize the soil. Peasants' land did suffer from exhaustion, because landlords 'may always have held the best land in their villages and possessed more pasture than their tenants and also enjoyed the privileges of the fold, i.e. preferential claims to the manure of the village flocks'.[3]

More recently, evidence has been presented which suggests that a peasants' acre might have been at least as productive as a seigneurial one. Langdon's work on extents for debt shows almost similar productivity figures for landlord and non-landlord farms in the first half of the fourteenth century. Stone has reported some examples of peasants' yields that were much higher than those of nearby demesnes.[4] Sapoznik has studied peasant agriculture for the manor of Oakington, Cambridgeshire, for the period 1360–99, using data from tithe accounts and manor court rolls. Combining these results with her estimates of the size of the tithed land, she showed average peasants' output per arable acre to have been at least 21 per cent higher than that of the demesne. The upper bound can be calculated to have been 81 per cent above the demesne sector.[5] Campbell has given examples of high land rents, which suggests that yields must have been above demesne level in order to have been profitable.[6] Elsewhere, Cauweberghe and Van der Wee found an inverse relationship between farm size and productivity for fourteenth-century Flanders.[7]

The availability of labour surely must have played an important role in this.[8] As Stone notes when discussing the poor yields on the manor of Hinderclay:

> While poor demesne yields at Hinderclay seem to have been mainly the result of deliberately low labour inputs, it is likely that inducement of working for themselves prompted local peasants to farm their land in a much more labour-intensive fashion, and they may well have achieved considerably higher crop yields as a result.[9]

Labour-intensive strategies like weeding, marling and the cultivation of legumes were all familiar methods of raising arable production. When it came to using them, the peasant sector

3 M. M. Postan, 'Medieval agrarian society in its prime: England', in M. M. Postan (ed.), *The Cambridge Economic History of Europe,* I, *the agrarian life of the middle ages* (1966), pp. 556–8.

4 John Langdon, 'Bare Ruined Farms? Extents for debt as a source for landlord versus non-landlord agricultural performance in fourteenth-century England', in Maryanne Kowaleski, John Langdon, and Phillip R. Schofield (eds), *Peasants and lords in the medieval English economy* (2015), pp. 59–82; David Stone, *Decision-making in medieval agriculture* (2005), pp. 269–72.

5 Sapoznik assumes 'that the land from which tithes were received fell between 696 and 1,044 acres'. Mean output for the demesne sector was 8.6 bushels per arable acre. She calculates mean output for the non-demesne sector to have been 10.4 bushels per arable acre, using the upper boundary of 1044 acres. Using the lower boundary of 696 acres therefore makes 10.4 × 1044 / 696 = 15.6 bushels per arable acre. See Alexandra Sapoznik, 'The productivity of peasant agriculture: Oakington, Cambridgeshire, 1360–99', *EcHR* 66 (2013), pp. 521, 530.

6 Bruce M. S. Campbell, 'Agricultural progress in medieval England: Some evidence from eastern Norfolk', *EcHR* 36 (1983), p. 40.

7 Bruce M. S. Campbell, *English seigniorial agriculture, 1250–1450* (2000), p. 71.

8 See, for example, Eona Karakacili, 'English agrarian labor productivity rates before the Black Death: a case study', *JEcH* 64 (2004), p. 3;

9 David Stone, 'Medieval farm management and technological mentalities: Hinderclay before the Black Death', *EcHR* 54 (2001), p. 635.

clearly had an advantage over the seigneurial because of the availability of labour. Even on some less obvious fertilization techniques, like the use of ashes from the fireplace, or the use of nightsoil, small farms undoubtedly had an advantage over large farms.[10]

With respect to the use of manure, however, the situation was much more complicated. Postan and Titow concentrated on sheep folding. Folding, however, was not the only animal husbandry system. It surely must have been an attractive one to lords because labour costs were minimal; other methods, although much more labour-intensive, were known and were in use, like collecting and spreading manure. Moreover, scholars disagree on the availability of manure. Postan's position on this has already been mentioned. By contrast, Slavin, comparing stocking densities between tenants and demesnes of Blackbourne Hundred, has found considerably higher figures for the peasant sector.[11] Besides, while Stone argues that peasants must have 'used all the manure that was available to them', Slavin is doubtful whether more manure would have led to higher yields, because of the risks of overmanuring and of parasitic diseases.[12] Compared to the 35-ton per acre of farmyard manure spread annually on one of the plots of the Broadbalk Continuous Wheat Experiment over more than a century, however, medieval amounts, as computed in this study, were rather small.[13] The high yields on Broadbalk's plot are therefore an indication that overmanuring could have happened only rarely in medieval England.[14]

Since animal manure was the main fertilizer, this study concentrates on its availability. It aims to check the assumption that when compared to lords' soil, peasants' soil was less fertile, by making a quantitative evaluation of the use of animal waste. In order to achieve this goal, the manure flows are modelled for two fictional manors, each possessing the major characteristics of the region they represent. By comparing of peasant land to demesne land within each model, the assumption can be checked for that particular model. Comparison of the two models can be used to gain insight into the scope and applicability of the results.

For purposes of modelling the manure flows, livestock size and stocking densities have to be estimated first. Therefore, after establishing values for the size of cattle, sheep and pigs in section I, section II deals with the relation between farm size and stocking densities. In section III two manor models are introduced to compare East Anglian farming to Midlands farming, each manor consisting of only three types of farms, namely half-virgates, cottages and a demesne. Attention is given to the quantities of grass, hay and straw, necessary to feed all farm animals. In section IV short term and long term fertilization figures are calculated for the three types of farms. Section V discusses the implications for grain yields, while section VI

10 For an introduction in fertilization techniques, see Robert S. Shiel, 'Improving soil productivity in the pre-fertiliser era', in Bruce M. S. Campbell and Mark Overton (eds), *Land, labour and livestock: historical studies in European agricultural productivity* (1991), pp. 51–77.

11 Philip Slavin, 'Peasant livestock husbandry in late thirteenth-century Suffolk: Economy, environment, and society', in Kowaleski, Langdon and Schofield (eds), *Peasants and Lords*, p. 14.

12 Ibid., p. 14; Stone, *Decision-making,* pp. 264–5.

13 D. S. Jenkinson, 'The nitrogen cycle in long–term field experiments', *Philosophical Trans. Royal Society of London. Series B, Biological Sciences,* 296, no. 1082 (1982), p. 564.

14 The nitrogen uptake of the crop for various treatments on Broadbalk fields are reported in J. Wolf and H. Van Keulen, 'Modeling long–term crop response to fertilizer and soil nitrogen, II, comparison with field results', *Plant and Soil*, 120 (1989), p. 27

discusses whether a shortage of accessible phosphorus rather than manure may have been the restraint on medieval agriculture. Section VII considers the implications of our findings for the minimum holding size necessary for subsistence, and for population numbers.

I

Before being able to evaluate the amount of manure that livestock produced, one has to determine their size, since the two are related. Zooarchaeological evidence shows that medieval horses, cattle, sheep and pigs were much smaller than contemporary English livestock. For instance, Thomas *et al*. analysed 7966 bone measurements from 105 sites in London for different periods between 1220 and 1900. Nineteenth-century cattle, sheep, pigs and domestic hens were found to have been some 10–13 per cent larger than they were in the thirteenth century.[15] Time series show increases in livestock size, occurring not only during the eighteenth and nineteenth century, but even hundreds of years earlier. Sykes collected data from hundreds of British assemblages, each containing bones stemming from the middle ages. She reports a size increase of a few per cent for cattle and pigs, in contrast to a slight decrease for sheep, during the late middle ages.[16] Thomas' study of animal bones from excavations of Dudley Castle, West Midlands, shows size increases for cattle, sheep and pigs of a few per cent during the fourteenth century.[17]

Besides these size changes in time, one has to be aware of regional variation too. Comparing animal remains from different English regions, David and Beckett show livestock to have been larger in central England than in peripheral regions. Cattle and sheep remains, found in Prudhoe Castle (Northumberland) and Launceston Castle (Cornwall) were some 8–10 per cent smaller than those from sites in York, Northamptonshire, Leicester and Norwich.[18]

All these results depend upon the comparison of skeletal remains. One should keep in mind that the result found is not independent of the type of bone, and the type of measure, that is chosen, since different bones do not scale exactly the same way. To give an example, when a species increases in size, the circumferences of the limb bones usually increase more than their length, since they have to carry more weight.[19] To combine the results for various types of bones, zooarchaeological scholars use reference skeletons, like Thomas did in his study of London sites. He compared the found cattle bones to those of a Chillingham bull, whose skeleton resembles that of medieval British cattle.[20] The live weight of this bull can be estimated, based on specific measurements of four of its limb long bones, to have been

[15] Richard Thomas, Matilda Holmes and James Morris, '"So bigge as bigge may be": tracking size and shape change in domestic livestock in London (AD 1220–1900)', *J. Archaeological Science*, 40 (2013), pp. 3315–18, 3321.

[16] Naomi Jane Sykes, *The Norman Conquest: a zooarchaeological perspective* (2007), pp. 3–6, 50–5.

[17] Richard Thomas, *Animals, economy and status: integrating zooarchaeological and historical data in the study of Dudley Castle, West Midlands* (c. *100–1750)* (2005), pp. 34–6, 43–44, 51–2, 132–4, 163, 189.

[18] Simon J. M. Davis and John V. Beckett, 'Animal husbandry and agricultural improvement: the archaeological evidence from animal bones and teeth', *Rural Hist*. 10 (1999), pp. 7–8.

[19] Per Christiansen, 'Scaling of mammalian long bones: small and large mammals compared', *J. Zool*., 247 (1999), pp. 333–48.

[20] Thomas *et al*., '"So bigge as bigge may be"', p. 3311; S. J. G. Hall, 'Park cattle', in G. B. Corbet and S. Harris (eds), The handbook of British mammals (Third edn, 1991), p. 538.

about 600 lb.[21] Since this value closely matches the reported maximum adult weight for Chillingham bulls in Chillingham Park, which is 661 lb, the estimated live weight may be expected to be quite reliable.[22]

For the period 1230–1350, Thomas compared 92 cattle bones to those of the Chillingham bull. Their measurements were, on average, 13 per cent smaller than those of the bull.[23] Since animals are three-dimensional objects, the mean weights for thirteenth-century cattle can be calculated to have been about 390 lb.[24] The live weight of an average thirteenth-century sheep can be estimated in a similar way to have been about 44 lb.[25] Comparing the two species, cattle were about nine times as heavy as sheep, which is in accordance with the observation that sheep were about half the height of cattle in the late middle ages.[26] Following the same procedure, pigs are estimated to have weighed some 73 lb.[27] However, this value probably is much too low, since pigs have much shorter legs relative to their weight than cattle and sheep. Its weight may be expected to be much closer to the weight of an African bush pig, whose skeleton is of about the same size, and for which Christiansen reports a weight of 167 lb.[28]

21 Limb bones are used to calculate bodyweight, using the allometric relationships between bone measure and weight for terrestial mammals that weight more than 50 kg. These relationships are of the form $L = c \cdot weight^b$, with b and c being constants. Christiansen presents two relationships per measure, leading to 258 and 259 kg when Humerus GL (Greatest Length) is used, 218 and 225 kg when Radius GL is used, 259 and 260 kg when Femur GL is used, and 368 and 332 kg when Tibia GL is used. The mean is thus 272 kg. For bone measures, see: Thomas *et al*., '"So bigge as bigge may be"', p. 3311. For allometric relationships see Per Christiansen, 'Scaling of the limb long bones to body mass in terrestrial mammals', *J. Morphology,* 239 (1999), p. 183.

22 300 kg. See Hall, 'Park cattle', p. 538.

23 For the period 1220–1300 the mean log–scaled value is −0.0622 . Therefore, the medieval bones are $10^{-0.0622} = 0.8666$ times the reference bones. Thomas *et al*., '"So bigge as bigge may be"', p. 3315.

24 In formula $L = c \cdot weight^b$ (see also n. 21), the constant b depends on the specific measurement that is used. For circumference measures, usually $b > 0.33$, for length measures, usually $b < 0.33$. Since Thomas' results are based on various measures, b is taken to be 0.33 , which leads to $600 \times 0.8666^3 = 390$ lb. For allometric relationships see Christiansen, 'Scaling of the limb long bones', pp. 167–90.

25 Using the allometric relationships for terrestrial mammals that weight less than 50 kg, are used to calculate the weight of the sheep that Thomas *et al.* use as the reference for sheep bones. Humerus GL leads to 11.3 and 11.4 kg, Radius GL to 15.3 and 16.0 kg, Femur GL to 12.1 and 12.2 kg, and Tibia GL to 19.1 kg. Calculating the mean, the sheep must have been some 14.0 kg. Since Thomas *et al.* found sheep of the period 1220–1300 to have been $10^{0.05} = 1.122$ times the reference sheep, their weight can be calculated to have been $14.0 \times 1.122^3 = 19.8$ kg; For bone measures, see: Thomas *et al*., '"So bigge as bigge may be"', pp. 3311, 3317; for allometric relationships see Christiansen, 'Scaling of the limb long bones', p. 183.

26 Gregory Clark, 'Land productivity in English agriculture, 1300–1860', in Campbell and Overton (eds), *Land, labour and livestock*, pp. 214–7; Annie Grant, 'Animal resources', in Grenville Astill and Annie Grant (eds), *The countryside of medieval England* (1988), p. 176.

27 Using the allometric relationships for all terrestrial mammals, we can calculate the weight of the pig that Thomas *et al.* use as the reference for pig bones. Humerus GL leads to 31.2 and 34.3 kg, Femur GL to 28.0 and 28.3 kg, and Tibia GL to 21.0 and 22.1 kg. Calculating the mean, the sheep must have been some 27.5 kg. Since Thomas *et al.* found sheep of the period 1220–1350 to have been $10^{0.0266} = 1.063$ times the reference pig, their weight can be calculated to have been $27.5 \times 1.063^3 = 33$ kg; for bone measures, see Thomas *et al*., '"So bigge as bigge may be"', pp. 3311, 3318; for allometric relationships see Christiansen, 'Scaling of the limb long bones', p. 175.

28 According to Thomas' figures, a thirteenth-century pig is $10^{0.0266} = 1.06$ times his reference pig, which has Humerus GL= 166 mm, Femur GL = 186.5 mm and Tibia GL = 169 mm. The African bush pig, described by Christiansen, has humerus length of 187.5 mm, femur length of 206 mm and Tibia length of 172 mm. For the size of the limb bones of the African bush pig (*Potamochoerus porcus*), Christiansen, 'Scaling of mammalian long bones', p. 336; for the weight of this species,

A different approach to arrive at the live weights of livestock starts from estimates of the weight of their meat. Clark has made very plausible estimates of the amount of meat of cattle, sheep and pigs, based on prices paid for living animals. Although already 25 years old, they remain the best available and have recently used as benchmarks by Broadberry *et al.* in their comprehensive study of *British economic growth*.[29] To arrive at these estimates, he equated the price of an animal to the value of its hide and meat, thus ignoring all its other parts. Comparing nineteenth-century mountain sheep with medieval sheep, he assumed that, since they had the same fleece weight, they both yielded the same amount of meat, which was 22 lb.[30] He used this weight to calculate the price of mutton. Assuming that the price of mutton, beef and pork were about the same, he calculated the yield of meat to have been 225 lb for oxen, 168 lb for cows and 64 lb for pigs.[31] These estimates are quite close to those that Barbara Harvey made, based on Stouff's figures for Provence's fourteenth- and fifteenth-century livestock: 240 lb of meat (including fat) for cattle, 24 lb for sheep and 50 lb for pigs.[32] What makes these figures even more plausible is that his figure for pigs equals the average amount of meat found on 656 pigs of Peterborough Abbey in the year 1309–10.[33]

To be able to convert the weight of meat into the live weight of an animal, one needs to know the meat weight-to-live weight ratio. For today's cattle and pigs, Belgian butchers reckon with 60 per cent; for Sudanese cattle, Dahl and Hjort mention the carcass, i.e. meat and bones, to be about 47 per cent of the live weight.[34] Since medieval animals were probably less well-fed than today's Belgian animals, a conversion rate of 47 per cent seems the most plausible.

Bones may be 10 per cent of the live weight. On the other hand, meat is not the only edible part of an animal. Fat, blood, tongue and liver may also have been 10 per cent of the live weight.[35] Therefore percentages of the edible parts might be estimated at 47 per cent, which, used on Clark's figures, makes live weights of 426 lb for cattle, 47 lb for sheep and 136 lb for pigs.[36]

The two approaches, the skeleton approach and the meat approach, produce estimates that are quite close for cattle and for sheep. For cattle the difference is less than 10 per cent, for sheep less than 7 per cent. Therefore these values are firmly established to have been 400

see: id., 'Scaling of the limb long bones', p. 170; for the size of pigs of the period 1220–1350, see Thomas *et al.*, '"So bigge as bigge may be"', pp. 3311, 3318.

[29] Stephen Broadberry, Bruce M. S. Campbell, Alexander Klein, Mark Overton, Bas van Leeuwen, *British economic growth 1270–1870* (2015), p. 109.

[30] This weight is almost 40 per cent below the 36 lb that Kitsikopoulos suggests, who refers to the carcass weight of current nomadic sheep that are given by anthropologists Dahl and Hjort, to be in the interval 10–25 kg. Deducting 8% for bones, makes the amount of meat to be in the interval 20–51 lb, on average 36 lb. See Kitsikopoulos, 'Standards of living', p. 240; Gudrun Dahl and Anders Hjort, *Having herds: pastoral herd growth and household economy* (1976), pp. 202–3.

[31] Clark, 'Land productivity', pp. 214–7.

[32] Barbara Harvey, *Living and dying in England, 1100–1540; the monastic experience* (1993), pp. 228–30.

[33] Kathleen Biddick, *The other economy, pastoral husbandry on a medieval estate* (1989), p. 124.

[34] Dahl and Hjort, *Having herds*, p. 165; An Derden, Judith Schrijvers, Michel Suijkerbuijk, Anouk Meulebroecke, P. Vercaemst, R. Dijkmans, *Best Beschikbare Technieken voor de slachthuissector* (Best techniques for the slaughterhouse) (2003), pp. 77–8.

[35] Ibid.

[36] This live weight for cattle is far below the one that Kitsikopoulos uses which is based upon a note from Howell that 'they would have been much smaller than the modern cow, seldom weighing as much as 1000 pounds'. Cicely Howell, *Land, family and inheritance in transition: Kibworth Harcourt, 1280–1700* (1983), p. 98; Kitsikopoulos, 'Standards of living', p. 259.

lb for cattle and 45 lb for sheep. For pigs the results are quite different. The meat approach leads to a value almost halfway between the two skeleton approaches, leading to 73 lb and 167 lb respectively. In the rest of this article, the live weight of an adult pig is assumed to have been 136 lb.

II

Although a large farm usually had much more livestock than a small farm, when counting the amount of livestock per arable acre, the opposite is usually true.

Campbell found an inverse relationship between stocking density and grain acreage, using data collected from manors in ten counties around London, in the research project 'Feeding the City'.[37] He calculated the mean stocking densities for 179 demesnes, sorted in seven size categories, as displayed in Figure 1. For the period 1288–1315, small demesnes, tilling less than 100 acres of grain, held, on average, 0.7 Livestock Units per grain acre, while very large demesnes, tilling more than 400 acres, only held, on average, 0.3 Livestock Units per grain acre.[38] Therefore, when the grain acreage increased some five to tenfold, stocking density more than halved, the multiplication factor being 0.7/0.3 = 2.3.

Overton and Campbell used information in accounts of medieval demesnes and probate inventories of early modern farms in Norfolk to calculate stocking densities for four different periods.[39] Although the results are not as smooth as those for the 'Feeding the City' counties, the tendency is the same for all four periods, namely that large farms have lower stocking densities than small ones. Comparing a small farm to a ten times larger farm, the multiplication factor is 1.2 – 2.3, depending on the period.[40] For the period currently under study, i.e. 1250–1349, this factor is 1.4.

One should be aware that the differences in stocking density described above might depend not on the size of the farms, but instead on geographical differences. In the case of a countrywide comparison, it might be these differences that would be decisive.

Although not in England, the study of the Flemish region of Oudenaarde may shed some light upon this matter. Since the region is quite small, geographical differences play a minor role in differences in stocking densities. Thoen sorted stocking densities for 93 early-modern farms into six categories. Comparing very small holdings (0–1.2 acres) to holdings that were ten times larger (2.5–10 acres), the multiplication factor is 1.5 for the period 1503–1520, and

[37] Campbell, *English seigniorial agriculture*, pp. 31–2, 179.

[38] Ibid., p. 181.

[39] Overton and Campbell use a weighting, based on modern food requirements, as follows: where a horse weighs 1.0, mature cattle (oxen, cows and bulls) weigh 1.2, immature cattle 0.8, sheep and swine 0.1; see Mark Overton and Bruce M. S. Campbell, 'Norfolk livestock farming, 1250–1740: a comparative study of manorial accounts and probate inventories', *J. Historical Geography*, 18 (1992), pp. 387–90.

[40] The choice of the compared categories is made in such a way to smoothen the tabulated values. For the medieval periods, the category 'less than 50 cereal acres' is compared to the categories from 200 to 300 acres, which leads to a multiplication factor of 1.4 for 1250–1349, and to 1.2 for 1350–1499. For 1584–1660, 'less than 12.5 acres' is compared to the categories 25 to 100 cereal acres, which leads to a multiplication factor of 2.3. For 1584–1640, 'less than 12.5 acres' is compared to '50–75 acres', which leads to a multiplication factor of 2.1 for 1660–1740. See Overton and Campbell, 'Norfolk livestock farming', pp. 388–90.

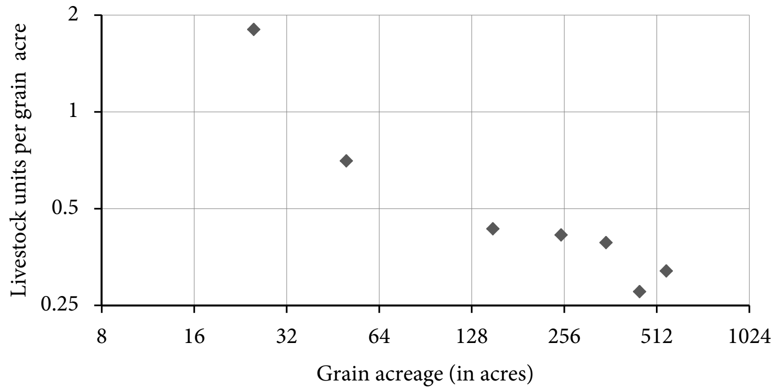

FIGURE 1: Stocking density and grain acreage on 179 demesnes in the FTC counties, 1288–1315, subdivided in groups according to the grain acreage.

Groups: < 50, < 100, 100–200, 200–300, 300–400, 400–500, 500+
Note: Both axes are in logarithmic scale. Each point corresponds to one group.
Source: Campbell, *English seigniorial agriculture*, p. 181.

1.9 for the period 1541–50.[41] The results, therefore, are similar to those for England and for Norfolk.

Quite recently, Slavin has studied stocking densities for Blackbourne Hundred, Suffolk, at the end of the thirteenth century, by analysing the 1283 tax list. Although the list has been studied by many scholars over the past hundred years, it is so rich with information that it can still shed new light on the peasantry at that period. The Blackbourne list is an inventory of all the movable goods of 1392 taxpayers in the Hundred, to be levied at a thirtieth part. It gives the number of horses, cattle, swine and sheep, and moreover the amount of cereals and legumes every taxpayer possessed at the octave of St Hilary, i.e. 20 to 26 of January. The reliability of tax lists in general has been frequently discussed.[42] In the case of this list Langdon has shown that at least 30–35 per cent of the households were missing for some villages.[43] Hadwin argues that all figures drawn from tax rolls must be used with caution, since tax evasion played an important role.[44] However true this may be, it does not hinder the way these figures are used in this study. Just as in Langdon's study, the emphasis is not on absolute numbers, but instead on relative numbers, since in the present study, stocking densities on peasants' holdings are compared to those on demesnes.

41 Thoen uses a weighting of Livestock Units similar to Titow's, counting every mature horse, and cattle as 1.0, every immature animal, and every sheep and pig as 0.25 Livestock Unit. Erik Thoen, *Landbouwekonomie en bevolking in Vlaanderen gedurende de late Middeleeuwen en het begin van de Moderne Tijden, testregio: de kasslerijen van Oudenaarde en Aalst,* band II [Agricultural economy and population of Flanders during the late middle ages and the early modern period: the regions Oudenaarde and Aalst] (1988), pp. 792–5.

42 For a recent discussion see Hugo La Poutré, 'The contribution of legumes to the diet of English peasants and farm servants, c. 1300', *AgHR* 63 (2015), pp. 19–38; Slavin, 'Peasant livestock husbandry', p. 12.

43 John Langdon, *Horses, oxen and technological innovation: the use of draught animals in English farming from 1066 to 1500* (1986), pp. 184–5.

44 J. F. Hadwin, 'The medieval lay subsidies and economic history', *EcHR* 36 (1983), p. 205.

Willard, studying tax lists after 1290, argued that the cereals and legumes assessed were only the surplus that a taxpayer had for sale, i.e. yields net of family consumption.[45] Elsewhere we have shown that this argument does not hold for the Blackbourne tax list, since the amounts assessed were much too high. Accepting Langdon's estimate of missing households, and keeping in mind that part of the harvest was already consumed at the time the assessment was undertaken, we estimated that the assessed amounts did match the quantities needed for consumption by the inhabitants and livestock of the Hundred, not counting the amounts for sowing.[46] For Willard, exemption of seed is highly probable, 'on the ground that it was a part of his waynage and needed for "carrying on the agriculture which was his livelihood"', in the same way as farming equipment (such as ploughs) and household goods (such as cooking vessels) were not assessed.[47] Slavin maintains that 'the language of the instructions given to local tax assessors implies that only processed food and drink, ready for immediate consumption, was not to be taxed'.[48] The assessed grain of a taxpayer may therefore be used to estimate his harvest. Assuming that crop yields on demesnes and peasants' holdings were about the same, Slavin uses the amount of grain as an indication of the sown acreage of the farm.[49] Under this assumption, he finds stocking densities of peasants' holdings to have been 2.2 times higher than those of demesnes.[50]

It is important to realize that, if – as this study will show – peasant holdings had much higher arable output per acre than demesnes, Slavin's method will have overestimated the size of the smaller holdings, and therefore will have underestimated the stocking densities of these holdings. The difference in the stocking densities between peasant and demesne holdings would have been even larger than he allowed.

Slavin mentions the existence of an inverse relationship between stocking density and size of the arable, but does not give any specifications.[51] However, since Powell has tabulated the possessions of all 1392 taxpayers, the households can easily be sorted according to the amount of grain they possessed.[52]

The relationship between the amount of grain and the number of Livestock Units per quarter of grain that a taxpayer possessed, are given in Figure 2. Detailed information on the subdivision into groups can be found in the Appendix. In order to appreciate Figure 2, it is important to realize that the poor were exempt from this tax. The lower threshold for inclusion in the tax lay at half a mark, i.e. at 6*s.* 8*d.*[53] Only nine persons in the list have possessions which are estimated to have been below this threshold. In terms of grain, this threshold lay at 1.7 quarters, taking a quarter of grain to be worth, on average 3*s.* 10*d.*[54] Anyone who owned

[45] James Field Willard, *Parliamentary taxes on personal property, 1290 to 1334* (1934), pp. 81–5.

[46] La Poutré, 'Contribution of legumes', pp. 30–2.

[47] Willard, *Parliamentary taxes,* pp. 81–5; Langdon, *Horses, oxen*, p. 82.

[48] Slavin, 'Peasant livestock husbandry', p. 12.

[49] Tithes play no role in this comparison, since they were exempted from this tax. Only temporalities were taxed. Edgar Powell, *A Suffolk Hundred in the year 1283* (1910), p. xi.

[50] Slavin used the same weighting of Livestock Units as Overton and Campbell (see n. 39); see Slavin, 'Peasant livestock husbandry', pp. 12–14.

[51] Ibid., pp. 14–5.

[52] Powell, *Suffolk Hundred*, pp. 122–200.

[53] Ibid., p. xii.

[54] The average price per quarter of corn as mentioned in the tax list, weighted according to the sums of the amounts per taxpayer, i.e. 966 qtr of wheat, 1342 qtr of rye, 4970 qtr of barley, 1379 qtr of oats, 1163 qtr of peas and beans. For prices see Powell, *Suffolk Hundred*, pp. xxiii–xxiv.

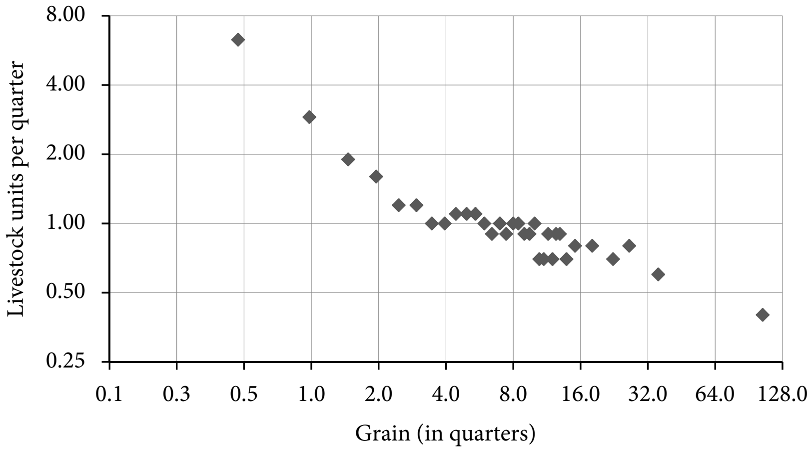

FIGURE 2: 1298 taxpayers of Blackbourne Hundred, subdivided in groups according to the total volume of cereals and legumes in their possession.

Note: Both axis are in logaritmic scale. Each dot corresponds to one group.
Livestock units are weighted according to the scheme of Overton and Campbell: horses × 1, cattle × 1.2, immature cattle (*vituli, vitule, bouiculi, iuuencule*) × 0.8, sheep × 0.1, swine × 0.1.
Source: Data presented in the Appendix, drawn from Powell, *Suffolk Hundred*.

less than 1.7 quarters of grain must have been exempt from this tax when he did not possess any animals.

Evidence from heriots shows that a considerable section of the peasantry had no livestock at all.[55] Most of them probably held no, or very little, arable land and therefore did not appear in the tax list.

Because of this exclusion of holdings without animals, the first two dots in Figure 2 lie much higher than they would have been if no one had been exempt. We need to note especially the 94 taxpayers who had less than 0.25 quarters of grain. Although hardly possessing any grain, they had to contribute to the subsidy because they owned at least one animal. Since 93 of them did not possess any grain at all at the time of the tax assessment, the number of Livestock Units per quarter of grain is a quite meaningless quantity for this category, since the denominator of this quotient is close to zero. If all, or even just one, of the exempted smallholders without any animals in this category had been included in the calculation, the quotient would have been quite different. They are therefore omitted from Figure 2.

What is clear from Figure 2 is that, on average, if a person A possessed one tenth of the amount of grain of person B, A's number of Livestock Units per quarter of grain would have been twice that of B. Following Slavin in assuming similar crop yields for demesnes and peasants' holdings, the multiplication factor for stocking densities, therefore, is 2, when comparing a holding to one that is ten times as large.

[55] Christopher Dyer, 'Farming techniques, the West Midlands', in H. E. Hallam (ed.), *Agrarian history of England and Wales, II, 1042–1350* (1988), p. 377.

Of course, due to infectious diseases, absolute numbers on livestock could fluctuate heavily from one year to another, as it did when scab struck English sheep in 1279–80.[56] Such disasters, however, struck seigneurial and peasant flocks alike. The same holds for fluctuations in yields or cereal prices. Thus their effect on relative numbers like the multiplication factor must have been a minor one. Since, however, the seigneurial sector is considered to have been able to restock more quickly after disasters than the non-demesne sector, the stocking densities on peasant land relative to those on demesne land, might have been even higher before 1279. Keeping that in mind, a multiplication factor of two might have been somewhat too low before the scab epidemic.

The Blackbourne figures are thus in line with the inverse relationship between farm size and stocking density for demesnes within the FTC-counties between 1288 and 1315, and for early modern Norfolk farms. Between 1250 and 1349, the inverse relationship for Norfolk was similar, although the multiplication factor was somewhat lower. All our evidence therefore points to the conclusion that peasant farms around 1300 had higher stocking densities than demesnes did, the multiplication factor being close to 2.

Based on the early modern Norfolk results, Broadberry *et al.* assume that, on non-demesne lands, stocking densities of cattle were 2.7 times as high, stocking densities of swine even four times as high, as they were on demesnes.[57] Compared to the evidence presented above, these figures are most probably somewhat too high.

III

Research on thirteenth-century agricultural practices has revealed geographical variation in many aspects of arable and livestock husbandry, not only from county to county, but also within counties. Holding size could even vary among manors belonging to the same estate. Harvey has tabulated the size of holdings (cottages excluded) on 24 manors of Westminster Abbey. Although a half virgate was the most common size in the early fourteenth century, the manors of Bourton-on-the-Hill, Gloucestershire, and Launton, Oxfordshire, had only virgates, and no half virgates at all.[58]

Besides holding size, field systems, cropping practices, the use of the fallow, the ratio of cattle to sheep, even the amount of seed sown per acre, all varied from manor to manor. Even within Norfolk, there was no single definition of the fold privilege:

> The lord's foldsoke was nothing so simple a monopoly as writers have assumed. To begin with it was often not confined to sheep. At Feltwell, Northwold, and Bridgham, in 1221–2, all the *averia* of the bond tenants, except their cows, lay in the lord's fold, but at Bridgham only the sheep lay there the whole year. The other cattle lay there only between Whitsuntide and Martinmass, and for the rest of the year the tenant paid a penny each to have them himself. At Bradfield if the tenant had sheep in the lord's fold he led them there on the Vigil

56 Slavin, 'Peasant livestock husbandry', p. 11.

57 Broadberry *et al.*, *British economic growth*, pp. 103–5.

58 Of 581 enlisted holdings, 18 were above virgate size, 188 were virgates or 3/4 virgates, 300 were 2/3 or 1/2 virgates, 62 were 1/3 or 1/4 virgates, 13 were smaller. See Barbara Harvey, *Westminster Abbey and its estates in the middle ages* (1977), pp. 438–42.

of Michaelmas and took away the breeding ewes at Candlemas and kept them until the next Michaelmas. At Northwold the free tenants had their own foldsoke, and this was probable the general rule.[59]

However, since the present study aims to prove one specific aspect, namely the availability of manure, a theoretical model is best suited for this purpose.

Because of the relationship between farm size and livestock density, it is instructive to compare three types of farms, namely a demesne, a half-virgate and a cottage. Assume a manor that contained 600 acres of arable. Of these, 150 acres belong to a demesne of average size, the rest belonged to 27 half-virgates, each holding 15 arable acres, and 30 cottages, cultivating 1.5 arable acres each, all in a three-course rotation system.[60] The demesne therefore contained one fourth of the arable, which was the average ratio for England.[61] The ratio of cottages to total holdings is consistent with the findings of Kanzaka, who analysed the Hundred Rolls of 1279–80. About 48 per cent of holdings held less than six acres of arable and meadow; together, these smallholders tilled only 6 per cent of all peasant land.[62] Campbell has estimated that, at the average lay manor, 60 per cent of peasant land was freehold land and about 40 per cent villein land.[63] Therefore, 16 out of 27 virgates in the model, and 18 out of 30 cottages, belong to free men.

According to the inverse relationship for stocking densities and farm size found above, the stocking densities on the model half-virgate were twice the demesne's, on the model cottage they were even four times as high. Campbell found that, on average, an English demesne held 4.4 horses, 22.3 cattle (of which 11.5 were oxen), 87.4 sheep and 11.9 swine per 100 sown acres, thus 0.37 Livestock Units per sown acre.[64] It is reassuring that the same figure is found when the stocking density is calculated from the Blackbourne list for large farms.[65] Using Campbell's figures for the model demesne and assuming that the stocking densities at half-virgates were twice – for cottages even four times – those of the demesne, then for every animal held by the lord there were 6.6 animals held by his peasants. The model manor therefore contains 33 horses, 169 cattle, 664 sheep and 90 swine. It will be specified in two variants, namely a Midlands manor and an East Anglian manor.

(a) The Midlands manor

Howell has described animal husbandry at Kibworth Harcourt, Leicestershire, in great detail. Just as Kitsikopoulos does in his peasant budget model, Kibworth's routine for cattle and sheep is applied to the Midlands manor.[66] Howell found that cows were held in their stalls

[59] H. E. Hallam, 'Farming techniques, eastern England', in Hallam (ed.), *Agrarian history*, p. 282.

[60] Mean demesne size for England is 100–200 sown acres; see Campbell, *English seigniorial agriculture*, p. 69.

[61] Broadberry *et al.*, *British economic growth*, p. 82.

[62] Kanzaka, 'Villein rents', p. 599.

[63] Bruce M. S. Campbell, 'The agrarian problem in the early fourteenth century', *Past and Present*, 188 (2005), pp. 24–7.

[64] Campbell, *English seigniorial agriculture*, pp. 124–5, 136–7.

[65] Since the Blackbourne list is an inventory of possessions at the end of January, the amount of grain may have been one third lower than it was directly after harvest. This, in combination with a mean yield around 13 bushels per sown acre, leads to a conversion rate of 0.9 sown acre per possessed quarter. According to figure 2 therefore a demesne with 100 sown acres would have had about 0.4 Livestock Units per sown acre. Mean yield is calculated from figures in Kitsikopoulos, 'Standards of living', p. 239.

[66] Howell, *Land, family*, pp. 97–100; Kitsikopoulos, 'Standards of living', pp. 258–9.

at Kibworth Harcourt, Leicestershire, from the end of October until 24 June, with a short interruption in the first week of May. Besides that, they were kept on pasturage for three months, and on the stubble for one month. Sheep, on the other hand, were kept outside for most of the year. They were held on the fallow for seven months and on the stubble after harvest for about three months.[67] The other two months, they were kept on pasturage or on dry feed.

Before being able to calculate how much manure and nutrients were deposited on the arable, one has to draw up an inventory of the feed quantities necessary. The three main foodstuffs for herbivores like cattle and sheep, are grass, hay and straw. They provide them with energy and proteins. Besides these three foodstuffs, cereals and legumes might be given, but only in small amounts. Langdon reports that oats formed no more than 3.3 per cent of total feeding budget for oxen, at 'certain Archbishopric of York Manors', between November 1373 and May 1374.[68] Since oxen were used as working animals who performed better when given some high-energy foodstuffs, the rest of the cattle, and the sheep, must have been given even less grain. Therefore, in what follows, grain is excluded from the calculation.

The ratio of protein to energy varies from foodstuff to foodstuff. An ox that eats only straw would have a protein deficiency, an ox that eats only hay or grass would consume more protein than necessary. Based on the necessary amounts of protein and energy, the ideal mix of grass, hay and straw can be calculated for cattle of live weight W (in kg), using formulae from today's Dutch livestock farming for cattle that are kept in a stall, not used as working animals, and not in their gestation or lactation period:[69]

$$\text{Necessary digestible proteins} = (2.75 \times W^{0.5} + 0.2 \times W^{0.6})/0.67$$

$$\text{Necessary Energy} = 41.4 \times W^{0.75}$$

For cattle of 182 kg (= 400 lb) kept in a stall all day, on a diet of only hay and straw, one can calculate from these formulae that they should be given 4.0 lb of hay and 4.8 lb of straw per day.[70] Therefore, 55 per cent of this hay-straw diet would consist of straw. Since this calculation only keeps track of the amount of straw that was consumed, neglecting the amount used for bedding, the quantity of straw provided per animal must have been higher. Therefore, such a percentage is in agreement with the feeding costs for oxen on manors of the archbishopric of York in 1373–4. Langdon found the costs for straw for these manors to have been, on average, 67 per cent of total costs for oxen, against 30 per cent for hay and 3 per cent for oats.[71] Since hay and oats were more expensive than straw, the percentage of

[67] Howell, *Land, family*, pp. 98–100.

[68] John Langdon, 'The economics of horses and oxen in medieval England', *AgHR* 30 (1982), p. 34.

[69] The formulae for cattle have two variables which are live weight and weight of produced milk. For oxen, this last variable obviously is zero. Therefore this variable is not considered here. *Tabellenboek veevoeding* (*Tables for livestock feed*), *2012* (2012), pp. 8–10.

[70] 1.8 kg of hay, and 2.2 kg of straw, can be calculated from the following figures: such cattle need 2051 VEM energy and 62.1 g of protein per day. ('VEM' is a unit of the energy of feed, used in Dutch livestock farming.) The energy content of hay is 631 VEM/kg, of straw 412 VEM/kg (377 VEM for wheat straw, 446 VEM for oat straw). The protein content of hay is 34 g/kg, none for straw. *Tabellenboek veevoeding*, pp. 102–9.

[71] Langdon, 'Economics of horses', p. 34.

straw in the feed must even have been well above 70 per cent.[72] A large part of this feed was transformed into manure. Albrecht Thaer, the famous German agronomist, found in the early nineteenth century that manure production for cattle is 2.3 times the amount of dry feed, a ratio that is still employed in agronomy today, and is also used by Kitsikopoulos in his peasant budget model.[73] Using this rule on the mentioned diet, cattle produced 5.1 per cent of their live weight per day. This figure is a little below the 6.0 per cent for today's beef cattle, as given in Table 1.[74] However, since cattle, kept outside, need 20 per cent extra feed, the difference between the two figures can easily be explained.[75]

Using Kitsikopoulos' estimate of 1171 lb straw per sown acre and assuming that peasants' yields were as low as demesne yields, an acre produced enough straw to feed one stall-fed ox or cow for eight months.[76] The arable of the demesne (0.22 cattle per sown acre) and of the half virgates (0.44 cattle per sown acre) thus produced more than enough straw for their cattle, leaving thousands of pounds for sheep, horses and pigs. According to these figures, the cottages (0.89 cattle per sown acre) barely produced enough straw to feed their cows. If, however, peasants' yields were much higher than those of the demesne, much more straw was produced. Furthermore, besides their own production of straw, these cottagers may have received it as a payment for harvesting labour, they may have cut it from other ones' property, or they may have compensated this shortage by giving extra hay or green waste from their gardens. On top of that, 'It should be remembered that the mediaeval oat plant certainly had a large proportion of straw to grain'.[77]

For the production of hay, Kitsikopoulos relies on Howell's guess: 'Now an acre of good meadows today can yield as much as five tons, but one would still not expect to get more than one ton of old meadow', thus 2240 lb of hay, which is almost equal to the amount Stone has found for Wisbech Barton in the 1340s.[78] Combined with a consumption of 979 lb of hay per animal, makes a total of 74 acres of meadow to feed all 169 cattle on the manor.[79] The model manor therefore needs at least one acre of meadow for every eight acres of arable. According to the map provided by Campbell, such a ratio can be found in many parts of a broad belt

72 Gregory Clark's price series gives the price of hay to have been 4.4*s.* per ton, for straw, 1.2*s.* per load in 1300. Accepting Harry Kitsikopoulos' assessment that a cartload might have been weighed about 1200 lbs, the price per lb of hay thus would have been twice as high as the price of straw, in which case even 80 per cent of the oxen's feed (expressed in weight) would have been in straw on the manors that Langdon investigated. See Gregory Clark, 'England, prices and wages since the 13th Century', Global Price and Income History Group, University of California, Davis (2006), gpih.ucdavis.edu/Datafilelist.htm; Kitsikopoulos, 'Standards of living', p. 246.

73 Peter Hall (ed.), '*Von Thünen's isolated state*' (1966), pp. 42–3; for modern use of the rule for cattle, see the website of the department of agriculture and fisheries of Queensland, www.daff.qld.gov.au/environment/intensive-livestock/cattle-feedlots/managing-environmental-impacts/manure-production-data; Kitsikopoulos, 'Standards of living', p. 259.

74 Calculated from figures in: *Livestock Waste Facilities Handbook* (third edn, 1993), p. 2.1.

75 *Tabellenboek veevoeding*, p. 10

76 Kitsikopoulos mentions 14,057 lb for 12 sown acres: 'Standards of living', p. 258.

77 Robert Trow-Smith, *A history of British livestock husbandry to 1700* (1957), p. 116.

78 Stone finds, averaged over 8 years, 2 cartloads of hay per acre. Kitsikopoulos assumes a cartload to have contained 1200 lb of hay. See: Howell, *Land, family*, p. 98; Kitsikopoulos, 'Standards of living', pp. 246, 258; Stone: 'The productivity of hired and customary labour: evidence from Wisbech Barton in the fourteenth century', *EcHR* 50 (1997), p. 644.

79 4.0 lb of hay per animal per day, during 8 months; $7.6 \times 22.3 = 169$ animals; $979/2240 \times 169 = 74$.

between Devon and Lincolnshire, in Yorkshire and in the northern counties. In the western and eastern parts of England, the situation was less favourable.[80] The problem could be solved by feeding extra grain, as can be concluded from Langdon's regional analysis of the quantity of oats consumed per ox. His figure for East Anglia is even as high as 0.87 quarters per ox per year.[81] If this amount were spread over eight months, a daily ration of 1.9 lb of hay and 5.8 lb of straw would be enough. Therefore, no more than one acre of meadow for every 17 acres of arable would be necessary to feed all the manor's cattle.[82]

Besides straw and hay, the manor needed enough pastures, heaths, marshes, fallow and stubble to feed its sheep. Kitsikopoulos suggests 1.66 sheep per acre for sheep grazing the fallow for seven months per year. However, he assumes sheep to have been much heavier than is found plausible in this study. Howell calculated a value of 1.5 sheep per acre out of figures that Hoskins gave for Leicestershire sheep at the end of the sixteenth century.[83] According to Broadberry *et al.*, however, sheep around 1600 were 60 per cent heavier than those around 1300.[84] Converting Howell's figure to sheep at 1300, makes 2.4 sheep per acre, which is close to the stocking density that Robert Grosseteste, a thirteenth-century bishop of Lincoln, noted in his rules for the Countess of Lincoln, 'that each acre of fallow ought to support yearly two sheep at the least'.[85] Since our hypothetical Midland manor had 200 acres of fallow at its disposal, the fallow could support at least 400 sheep during a year, or 686 sheep over seven months. The model manor therefore could indeed keep all its sheep on the fallow for seven months, as was done in Kibworth. It is therefore hard to believe that the model manor would have been short of pasture/common land to feed its sheep herd, especially since the sheep were also kept on 400 acres of stubble for a few months.

(b) The East Anglian manor

In East Anglia, where cropping patterns were more flexible, strips of arable land lying fallow often bordered on sown strips, thus posing serious problems for the grazing of the fallow. Under such circumstances, 'as soon as spring lambing was past, sheep were collected into communal flocks which were fed upon the heaths and sheepwalks by day and folded upon the fallow arable by night, whose soil they tathed with their treading, dung and urine', in movable folds.[86] Assuming lambing time to have taken one month, during which the herd stayed on a delimited piece of pasture, the sheep functioned as 'walking dung machines, to

80 Campbell, *English seigniorial agriculture*, pp. 73–6.

81 Langdon, 'Economics of horses', p. 33.

82 In this case, 0.85 kg of hay, and 2.65 kg of straw, would be sufficient per ox or cow. Since the density of oats is about 36 lb per bushel, the cattle consume 0.447 kg of oats per day. The amounts of hay and straw can then be calculated from the figures in note 70, supplemented by the figures for oats, namely 943 VEM of energy, and 74 g of protein, per kg. *Tabellenboek veevoeding*, pp. 74–5; for the density of oats, Bruce M. S. Campbell, James A. Galloway, Derek Keen and Margaret Murphy, *A medieval capital and its grain supply: agrarian production and distribution in the London region, c.1300* (1993), p. 41.

83 W. G. Hoskins, *Provincial England: essays in social and economic history* (1964), p. 151; Howell, *Land, family*, p. 99; Kitsikopoulos, 'Standards of living', pp. 240, 258.

84 Calculated from Broadberry *et al.*, *British economic growth,* p. 109.

85 Elizabeth Lamond (ed.), *Walter of Henley Husbandry, together with an anonymous husbandry, seneschaucie and Robert Grosseteste's Rules* (1890), p. 148.

86 Bruce M. S. Campbell, 'The regional uniqueness of English field systems? Some evidence from eastern Norfolk', *AgHR* 29 (1981), p. 17; id., *English seigniorial agriculture*, p. 154; id., 'Agricultural progress', p. 35.

transfer nutrients from the permanent pasture' to the fallow and stubble, for eleven months per year.[87]

An indication of the number of Livestock Units per acre of pasture can be found in a calculation that Salzman made for three manors of Crowland Abbey. An area of 5500 acres of common pasture could support 90 horses, 540 cows and oxen, 3600 sheep and 675 geese. Neglecting the geese, this equals 0.20 Livestock Units, or two sheep, per acre, which is the same as Robert Grosseteste's remark on fallow.[88] A second indication can be found in a survey of the estate of St Paul's Cathedral in Essex, 1222. The common marshes for sheep of *Tidwoldintum*, able to contain 240 sheep, were mentioned to have been 60 acres, thus four sheep per acre.[89] The model manor, containing 664 sheep, therefore had need for 166–332 acres of pasture. Considering Broadberry *et al.*'s estimate that, in 1300, in the densely populated eastern counties, almost 60 per cent of the area was used as arable land, the manor must have had enough pasture/common land to feed its sheep flock, but did not have much extra for the rest of its livestock.[90] Feeding extra straw, which was abundant at the demesne and the half-virgate, would compensate for the shortage of pasturage. Such a strategy is in line with Walter of Henley's advice on the dry feeding of sheep, namely that 'if straw be mixed with the hay they will chew it better because of the coarseness of the straw. And if you have lack of hay the pods and straw of peas are good for sheep'.[91] Besides that, it is hard to believe that farmers never left any livestock on the fallow or stubble at daytime, when they were running short of usable pasture. Only in very densely populated regions like eastern Norfolk, where the land was tilled so intensively that even on demesnes only seven per cent of the total arable land was left fallow, and where pastures, heaths and marshes were very limited, it might have been hard to find enough grazing land to feed such a flock.[92]

IV

At harvest, the grains of cereals and legumes were removed from the arable. Since these grains contained nutrients, the arable had to be fertilized to compensate for the lost main nutrients, namely nitrogen (N), phosphorus (P) and potassium (K). Besides grains, straw might have been removed too, to serve as livestock feed, or to cover the floor of a stall or a fold. However, after having been used this way, the straw-nutrients usually returned to the arable in the form of (farmyard) manure, therefore the arable did not need any compensation for the removal of straw.

Modern farmers apply fertilizer to their fields in order to restore or raise the nutrient content of nitrogen, phosphorus and potassium.[93] Locally, soils may be short of other nutrients, but in western European agricultural practice, these three are added on a yearly basis. The most deficient nutrient tends to determine the size of the yield. When the availability of this element

87 Campbell, 'Regional uniqueness', p. 18.

88 Trow-Smith, *History of British livestock husbandry to 1700*, p. 104.

89 Hallam, 'Farming techniques, eastern England', p. 304.

90 Broadberry *et al.*, *British economic growth*, p. 70.

91 Lamond (ed.), *Walter of Henley*, p. 31.

92 Campbell, 'Regional uniqueness', p. 21; id., 'Agricultural progress', p. 29.

93 E. I. Newman and P. D. A. Harvey, 'Did soil fertility decline in medieval English farms? Evidence from Cuxham, Oxfordshire, 1320–1340', *AgHR* 45 (2007), p. 120.

declines, plant growth and so its yield is reduced.[94] At harvest, when the grain is taken from the field, or after torrential rainfall, when nutrients may leach into the groundwater, the nutrient content of the soil is decreased. To prevent the nutrient balance in becoming negative, one has to restore the nutrient content. When livestock are grazed upon pastures or fed hay, and their dung is used to fertilize arable land, the quantity of all three main nutrients in the soil is raised. Such husbandry systems, namely stall feeding and night folding, will be discussed below. When cultivating legumes, the nitrogen content of the soil was raised, because these crops are capable of fixing atmospheric nitrogen.[95] Stone, Thornton, Brandon and Campbell have all mentioned the deliberate use of legumes as fertilizer on demesnes throughout England *c*.1300.[96]

Stone has gathered examples of peasants cultivating relatively much more legumes than their lords did.[97] In an earlier paper we have made a case for peasant holdings having proportionately at least twice as much legume under cultivation as demesnes.[98] In medieval times, when only a small amount of nutrient was subtracted year by year, time, restoring the soil's nutrient content was only important in the long term.

Unfortunately, not all nutrients in the soil are available for plant growth. Some become available only when they are released from the fine mineral material in the soil through weathering, others become available after decomposition of organic material like plant roots.[99]

Plant matter – roots, stems and leaves – when left to itself, may take quite some time to decompose, but when it is transformed into manure, the decomposition rate is increased.[100] Soil can thus be fertilized by letting livestock convert plant-parts like grass, hay or straw from this soil into manure, assuming of course that the manure is returned to the same soil. Although no nutrients are added in this process, the soil becomes more fertile since unavailable nutrients are made available in the short term. Besides the conversion of plants into manure, the use of marl also enlarges the amount of nutrients available, through increasing the pH of the acidic soil. The micro-organisms responsible for decomposing organic material, cannot function very well in an acidic environment. Manipulating the acidity this way can therefore increase the decomposition rate.[101] References to the use of this labour-intensive method are found in many thirteenth-century manorial accounts and court rolls.[102] A high, short-term, availability of nutrients in the soil is an important condition for high crop yields. If, however, a balanced fertility is not achieved, the soil will become exhausted in the long term.

Figures for the contribution from manure to short- and long-term fertilization, for contemporary livestock, are given in Table 1. These values are combined with the live weights of cattle, sheep and pigs, estimated in section I, to calculate the amount of manure and nutrients produced by farm animals around 1300.

94 Shiel, 'Improving soil productivity', p. 51.

95 Ibid., pp. 53–4.

96 Stone, 'Medieval farm management', p. 623; Stone, *Decision-making*, pp. 63–4; Christopher Thornton, 'The determinants of land productivity on the Bishop of Winchester's demesne of Rimpton, 1208 to 1403', in Campbell and Overton (eds.), *Land, labour and livestock,* pp. 195–6; P. F. Brandon, 'Demesne arable farming in coastal Sussex during the later middle ages', *AgHR* 19 (1971), pp. 125–8.

97 Stone, *Decision-making*, pp. 265–6.

98 La Poutré, 'Contribution of legumes', pp. 19–38.

99 Newman *et al.*, 'Did soil fertility decline', pp. 120–1.

100 Shiel, 'Improving soil productivity', p. 64.

101 Ibid., p. 63.

102 See, for example, Campbell, 'Agricultural Progress', pp. 33–4.

TABLE 1: Calculation of the amount of manure and nutrients for livestock *c.*1300 based on figures for today's livestock.

	Today's figures					*Estimated figures c.1300 in lb*				
	Daily manure-to-body ratio[b]	*Composition in %*				*Per individual*		*nutrient per year*		
		Moist[c]	N[b]	P[b]	K[b]	*Live weight*[a]	*Manure per day (dry weight)*[e]	N[f]	P[f]	K[f]
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
horse	0.051	80	0.59	0.14	0.49	400	4.08	43.9	10.4	36.5
cattle[d]	0.060	88	0.57	0.19	0.42	400	2.88	49.9	16.6	36.8
sheep	0.040	75	1.05	0.22	0.81	45	0.45	6.9	1.4	5.3
pig	0.065	91	0.70	0.22	0.46	136	0.80	22.6	7.1	14.8

Notes:

[a] For estimates of cattle, sheep and pigs, see text. For horses the weight of cattle is used.

[b] Calculated from figures in: *Livestock waste facilities handbook* (third edn, 1993), p. 2.1.

[c] Taken from ibid., p. 2.1.

[d] For cattle the figure for beef cattle are taken.

[e] Dry weight manure per day = (6) × (1) × [1 – (2) / 100]

[f] (8) = (6) × (1) × (3) / 100 × 365; (9) = (6) × (1) × (4) / 100 × 365; (10) = (6) × (1) × (5) / 100 × 365

Unfortunately, Newman gives figures for sheep that differ from those in Table 1.[103] He has based his values on ecological research undertaken on upland pastures in Snowdonia, claiming that, 'although the site is 490m above sea level, the soil and pasture vegetation are similar to old, unimproved pastures in lowland England'.[104] This claim, however, is unproven, since the area contains many types of grassland as soil moisture, soil nutrient supply and acidity varies from site to site.[105] Newman derives his values from observations of sheep numbers on small plots of 232 m² and from indirect measurements of consumed feed. Each month researchers harvested the vegetation grown within cages which – without protection – would have been eaten by sheep.[106] Armed with measurements of the nutrient content from the harvested plants, Newman calculated the nutrient content of the manure of these sheep. It is questionable whether these figures can be used to calculate the manure production per sheep, since the 32 observed plots of 232 m² each were not enclosed. Sheep therefore did walk in and out of these plots, could eat in one place and rest somewhere else. To illustrate this, sheep numbers per acre at noon were three times those around 6 o'clock. I therefore prefer the values in Table 1 that are derived from the livestock waste facilities handbook in preference to those of used by Newman.

103 For the period May to October, he reports 28.3g N, 2.48g P and 22.6g K, per adult sheep per day, which is two to three times the daily amount (averaged over the whole year) reported in *Livestock Waste Facilities Handbook*, p. 2.1; E. I. Newman, 'Medieval sheep-corn farming; how much grain yield could each sheep support?', *AgHR* 50 (2002), p. 167.

104 Newman, 'Medieval sheep-corn farming', p. 167.

105 D. F. Perkins, 'Snowdonia grasslands: introduction, vegetation and climate', in O. W. Heal and D. F. Perkins (eds), *Production ecology of British moors and montane grasslands* (1978), pp. 289–96.

106 S. Brasher and D. F. Perkins 'The grazing intensity and productivity of sheep in the grassland ecosystem', in Heal and Perkins (eds), *Production ecology*, pp. 354–62.

Different types of livestock management have different effects on the fertilization of the arable. When livestock was kept inside, in a stall, the produced manure had to be transported to the arable and spread upon it. This method was attractive, since this manure can easily be gathered in heaps and mixed with earth, as Walter of Henley advised in his thirteenth-century treatise on agriculture:

> Now I will tell you what advantage you will have from manure mixed with earth. If the manure was quite by itself it would last two or three years, according as the ground is cold or hot; manure mixed with earth will last twice as long, but it will not be so sharp.[107]

This method, however, required a lot of man-labour, since hay and straw had to be cut and transported to the stall, while manure had to be transported to, and spread on, the arable.

Stone has cast doubt on whether lords were willing to use all the stall manure they had at their disposal. Not using stall manure may seem a waste when considering the fertility of the soil, but it may be a rational decision if one is trying to maximize profit, as Stone found for the manor of Wisbech in the early fourteenth century. On most peasant holdings, however, the availability of labour was not a problem at all. Therefore, as Stone remarks, probably all of their manure was spread on the arable.[108] The values for stall feeding in Table 2, no. 1 and 4, are calculated under the assumption that, even on demesnes, all stall manure was used for fertilization. The differences between the demesne sector and the non-demesne sector thus must have been somewhat larger than the ones found in this study. Even when 100 per cent of the manure produced was used for fertilizing, only some 45 per cent of the main nutrients contained in cattle manure were derived from pasture lands or from grains, since more than half their feed consisted of straw.[109] For horse manure this percentage was much higher, since their feed contained much more grain, as Langdon shows in his comparison of horses and oxen.[110]

Newman has made detailed calculations for a second type of animal husbandry, namely for sheep that are kept on pastures, heaths, etc. during daytime and on a fold on the fallow or stubble at night, following the advice of the *Seneschaucie*, a thirteenth-century treatise on agriculture:

> And every night the cowherd shall put the cows and other beasts in the fold during the season, and let the fold be well strewed with litter or fern, as is said above, and he himself shall lie each night with his cows.[111]

Only one tenth of their feed was consumed in the fold whereas about half of their manure was deposited there.[112] Regarding long-term fertilization, therefore, 40 per cent of the main nutrients are transported from pasture to arable. With respect to short-term fertilization, 50 per cent of the produced manure is deposited on the arable. Both values are used in Table 2, no. 8. To keep the animals within a well-bounded area, they were kept within movable folds in the thirteenth century.[113] What made this husbandry system so attractive to lords was that labour inputs were minimal, since it was the sheep who were doing all the work. One just had

107 Lamond (ed.), *Walter of Henley*, pp. 19–21.
108 Stone, *Decision-making*, pp. 67–9, 264–5.
109 See section III.
110 Langdon, 'Economics of horses', pp. 31–40.
111 Lamond (ed.), *Walter of Henley*, pp. 112–3.
112 Newman, 'Medieval sheep-corn farming', p. 172.
113 Thornton, 'Determinants of land productivity', p. 200; Campbell, 'Regional uniqueness', p. 17.

TABLE 2: Efficiency of livestock management, namely the percentage of manure that is deposited on the arable, the percentage of nutrients in the produced manure, not coming from straw, that is transported to the demesne arable, on the Midlands manor, without the privilege of the fold.

				Manure on, nutrients transported to, the arable					
				Percentage		*Amount per year, in lb*			
No.	*Livestock* (1)	*Management Day // night* (2)	*Period (months)* (3)	*Manure*[a] (4)	*Nutrients*[a] (5)	*Manure dry weight*[b] (6)	N[c] (7)	P[c] (8)	K[c] (9)
	Lord's								
1	4.4 horses	Stall-fed	8	100 %	80 %	4368	103	24	86
2		Stubble // stall	1	62.5 %	30 %	341	5	1	4
3		Pasture // stall	3	50 %	40 %	819	19	5	16
4	22.3 cattle	Stall-fed	8	100 %	45 %	15,628	334	111	246
5		Stubble // stall	1	62.5 %	30 %	1,221	28	9	21
6		Pasture // stall	3	50 %	40 %	2,930	111	37	82
7	87.4 sheep	Fallow, Stubble // fold	10	62.5 %	30 %	7,477	151	31	116
8		Pasture // fold	2	50 %	40 %	1,196	40	8	31
9	11.9 pigs	Pasture // stall	12	50 %	40 %	1,737	108	34	70
	Peasants'								
10	28.6 horses	Stubble // stall	1	12.5 %	–10 %	444	–10	–2	–9
11	146.7 cattle	Stubble // stall	1	12.5 %	–10 %	1,606	–61	–20	–45
12	576.6 sheep	Fallow, stubble // fold	10	12.5 %	–10 %	9,865	–332	–67	–255
	Total					47,632	496	171	363

Notes:
[a] For an explanation of these figures, see text.
[b] (6) = (1) × (3) / 12 × (4) / 100 × Table 1 (7) × 365
[c] (7) = (1) × (3) / 12 × (5) / 100 × Table 1 (8)
(8) = (1) × (3) / 12 × (5) / 100 × Table 1 (9)
(9) = (1) × (3) / 12 × (5) / 100 × Table 1 (10)

to move the fold from one acre to the next. Folding therefore was an excellent way to keep down the costs of labour.

In a variant on this type of husbandry, livestock was not kept in a fold, but put in a stall at night. In this variant the advantage of low labour costs, of course, was lost. Instead, other benefits might have compensated for this loss, like keeping the animals dry under a roof, facilitating milking, or keeping working animals close to the farmyard. Therefore this variant seemed appropriate for cattle and horses. As long as all stall manure was spread upon the arable, the calculations for these two variants in Table 2, no. 3, 6, and 8, are the same.

In another variant, when livestock was grazed upon the pasture or heath, their dung was gathered and transported to the arable. Although Campbell found evidence that some demesnes used this method to fertilize the arable, it must have been mostly smallholders without any animals that turned to this labour-intensive method.[114]

A third type of animal husbandry, often mentioned, is the grazing of livestock upon the arable, namely on the fallow or stubble. In this husbandry system all of their urine and dung is directly deposited on the soil. Howell mentions that the fallow of Kibworth Harcourt was 'doled out as sheepwalks'.[115] Keeping in mind the advice of the *Seneschaucie*, namely that the animals should be kept in a fold at night, one should realize that the animals could move relatively freely during the day and were penned during the night. At the model manors, where 25 per cent of the arable was demesne land, an animal kept at the lord's fold left no more than 62.5 per cent of the daily manure on the demesne arable.[116] An animal kept at a peasant's fold, left 12.5 per cent of its daily manure on the demesne arable.[117] With regard to the main nutrients, livestock kept at the lord's fold transported net 30 per cent of the nutrients in its daily manure from other arable fields to the demesne fields.[118] In contrast, animals kept at a peasant's fold, transported net 10 per cent of the nutrients in their daily manure from the demesne to peasants' fields.[119] In Table 2, no. 7 and 12, these four percentages are used to calculate the contributions of this type of husbandry to demesne land. For the model's half virgate holding and cottage, these four percentages of course differ from the ones given above, since these holdings had respectively 2.5 and 0.25 per cent of the manor's arable land at their disposal.[120]

What is clear from Table 2, is that this type of husbandry was advantageous to a demesne with respect to short-term fertilization, but disadvantageous to long-term fertilization, since peasants possessed much more livestock to remove nutrients from the demesne arable than the lord did to bring nutrients to these fields. From this point of view, it would have been only fair for a lord to possess some kind of privilege of the fold.

In a variant on this type of animal husbandry, livestock were not kept in a fold, but put in a stall at night. This variant is found in Table 2, rows 2, 5, 10 and 11. Although the advantage of low labour costs was lost in this variant, all manure calculations are exactly the same as when the animals were locked in a fold. Therefore, whether cattle and horses were indeed put in a stall or in a fold, does not influence the results of this study.

For the Midland manor, livestock management is specified in Table 2. All calculations are done for demesne land. Calculations for the other farm types (half-virgates and cottages, villein and freehold) are similar, only animal numbers varying from type to type. While calculations on horses, cattle and pigs are kept the same for the two model manors, those on sheep deviate,

114 Campbell, 'Regional uniqueness', p. 22.

115 Howell, *Land, family*, p. 99.

116 50 per cent of its manure is deposited in the fold. Since 25 per cent of the arable is demesne land, only 25 per cent of the other 50 per cent of its manure is deposited on demesne land.

117 25 per cent of 50 per cent.

118 10 per cent of its feed was consumed in the fold, 90 per cent at daytime, of which only 25 per cent on demesne land. Therefore removing 10 + 0.25 × 90 = 32.5 per cent of its nutrients from the demesne, and depositing 62.5 per cent on the demesne, gives a net result of 30 per cent.

119 It consumed 25 per cent of 90 per cent of its feed on demesne land and deposited only 12.5 per cent of its manure on this land.

120 Half virgate: 50 + 0.025 × 50 = 51.25 per cent; 0.025 × 50 = 1.25 per cent; 51.25 – 10 – 0.025 × 90 = 39 per cent; 1.25 – 0.025 × 90 = –1 per cent. Cottage: 50 + 0.0025 × 50 = 50.125 per cent; 0.0025 × 50 = 0.125 per cent; 50.125 – 10 – 0.0025 × 90 = 39.9 per cent; 0.125 – 0.0025 × 90 = –0.1 per cent.

TABLE 3: Efficiency of livestock management, namely the percentage of manure that is deposited on the arable, the percentage of nutrients in the produced manure, not coming from straw, that is transported to the demesne arable, for the two theoretical manors, each without, and with extensive, privileges of the fold.

		Manure (dry weight); nitrogen; phosphorus; potassium in lb per sown acre per year			
		Midland manor		*East Anglian manor*	
		Without fold privilege	*With 10 months fold privilege*[e]	*Without fold privilege*	*With 12 months fold privilege*[f]
demesne[a]		476; 5; 2; 4	644; 11; 3; 8	363; 8; 2; 6	564; 15; 4; 11
half-virgate[b]	freehold	822; 15; 4; 11	822; 15; 4; 11	708; 17; 5; 13	708; 17; 5; 13
	villein	822; 15; 4; 11	702; 11; 4; 8	708; 17; 5; 13	565; 12; 4; 9
cottage[c]	freehold	1498; 34; 10; 25	1498; 34; 10; 25	1384; 34; 10; 26	1384; 34; 10; 26
	villein	1498; 34; 10; 25	1259; 26; 8; 19	1384; 34; 10; 26	1097; 25; 8; 18
Average peasant acre[d]		890; 17; 5; 12	836; 15; 5; 11	776; 19; 6; 14	712; 17; 5; 13

Notes:
[a] 4.4 horses, 22.3 cattle, 87.4 sheep and 11.9 pigs.
[b] 0.9 horses, 4.5 cattle, 17.5 sheep and 2.4 pigs.
[c] 0.18 horses, 0.89 cattle, 3.5 sheep and 0.48 pigs.
[d] Weighting 11 villein and 16 freehold half-virgates of 15 acres, and 12 villein and 18 freehold cottages of 1.5 acres each.
[e] All villein sheep during 10 months in the lord's fold, see table 2, row no. 7 and 12.
[f] All villein sheep during 12 months in the lord's fold, see table 2, row no. 7 and 12.

since calculations for our East Anglian manor are done for sheep that are pastured at daytime, and kept in a fold at night, all year round. In Table 3 the figures for long-term and short-term fertilization are displayed for the two model manors. Each model is displayed in two custom variants, namely one without any form of privilege of the fold, and one in which all the sheep of the lord's villeins were put in the lord's fold for as long as these sheep grazed upon the fallow (Midlands manor) or on pastures (East Anglian manor).[121] Since the right of the fold usually did not apply to freeholders, their sheep were not at the lord's disposal.[122] A note of caution on the interpretation of Table 3 is needed. In constructing this table, it is assumed that each arable acre was manured two out of three years, both years receiving precisely the same amount of manure, the third year receiving no dung at all. In practice such a strict regime was neither desired nor possible. Regarding the applicability of this study's results, however, deviations from this regime are of minor importance.

[121] Foldsoke may not always have been restricted to sheep, as examples by Hallam and Dyer show in Hallam, 'Farming techniques, eastern England', pp. 282–4; Dyer, 'Farming techniques, the West Midlands', p. 377.
[122] Hallam, 'Farming techniques, eastern England', p. 282.

V

Table 3 shows clearly that, when the demesne land is fertilized by its own livestock alone, it received far less manure than the soil of the half-virgate or cottage did, since the stocking density was so much lower. However, when an extensive privilege of the fold was the custom, a demesne acre received about as much manure and nutrients as a villein's half-virgate. Even then, an average peasant acre received at least 25 per cent more manure than a demesne acre.

Such an extreme situation, where villeins did not profit from their own sheep's dung, was probably only the case where they had to deal with 'an unscrupulous lord'.[123] For eastern Norfolk, Campbell notes that villein tenants had to place their sheep in the lord's fold for only a few months. Hallam gives examples of several different customs. At Pakenham the peasants could keep breeding ewes to themselves. At Blythburgh where 'they might keep their sheep between the Vigil of Whitsuntide and Michaelmas, at a payment of a penny for every four'.[124] According to the examples given by Hallam and Campbell, a privilege period of some five months seems about average. If the calculations above are adapted to this reality, then a demesne's fertilization would be depressed in favour of the villein farms, as can be seen in Figure 3. For a five months' privilege of the fold, an average peasant acre would receive 54 per cent extra manure on the Midland manor. On the East Anglian manor the difference would even have been 67 per cent.

However strict the privilege, on average a freeholder's half-virgate was better manured than a demesne. According to Table 3 the difference was at least 25 per cent. For cottages the difference was even larger. A cottage-acre could receive at least twice the amount of an acre of demesne. When indeed, as Postan proposed, the fertility of the soil was the major setback on medieval yields, it was demesnes, instead of peasants' holdings, that suffered from relative infertility.

For each of the main nutrients, the amounts added to the soil can be compared with the amounts taken from the soil at harvest, when grains and straw were taken from the fields. As mentioned before, straw can be left out of the equation, since it stayed on the field or its nutrients returned to the field in one form or the other. Therefore, it is enough to concentrate on the grains, net of seed. Using the values reported by Broadberry *et al.* on demesne yields, net of seed, for 1300–09, namely 7.8, 11.7 and 8.7 bushels per acre for wheat, barley and oats respectively, and assuming that half the sown area was in wheat, one quarter each in barley and oats, the grain would contain 6.3 lb of nitrogen, 1.3 lb of phosphorus and 1.9 lb of potassium per sown acre.[125] According to this calculation, Table 3 shows that nitrogen might have been the deficient nutrient for the demesne of the Midlands manor without the privilege of the fold. For all other farms considered, the balance was positive. Even when peasant holdings produced 50 per cent higher output, the fertility of their fields was guaranteed in the long term.

123 Campbell, 'Regional uniqueness', p. 18.

124 Ibid., p. 20; Hallam, 'Farming techniques, Eastern England', pp. 283–4.

125 For yields per acre see Broadberry *et al.*, *British economic growth*, p. 97; for densities of grains see La Poutré, 'Contribution of legumes', p. 24; for moisture content of the grains I assume the usual 15 per cent; for nutrient content of grains see Newman, 'Medieval sheep-corn farming', p. 171.

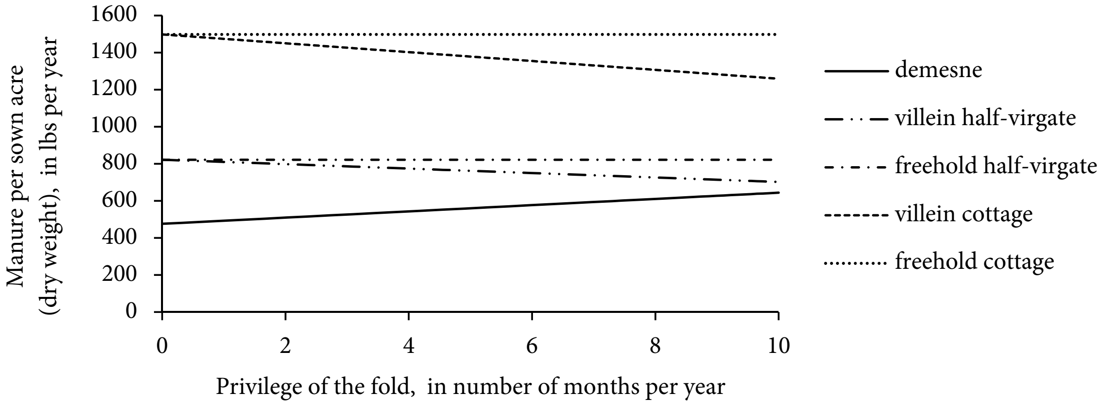

FIGURE 3: The relation between the amount of manure per sown acre and the number of months that the privilege of the fold holds at the theoretical Midland manor.

Source: Table 3.

This study therefore does not support Postan's view that peasant land deteriorated in the long term at the end of the thirteenth century. In fact, it reverses it. It was peasant land, rather than demesne land, that must have been in better heart.

VI

One question has been neglected so far in the calculations in this study. As is well known, faeces and urine easily release ammonia into the air or into runoff, especially when they are in open contact with air, i.e. not mixed with straw or earth or the like or exposed to rain. Since ammonia contains nitrogen, these losses of nitrogen can be considerable and this may have been the reason why pre-modern agriculture had to deal with nitrogen deficits. Walter of Henley's advice to 'cause your sheepfold to be marled every fortnight with clay land or with good earth, as the cleansing out of ditches, and then strew it over', points to an important agricultural practice to limit this kind of loss.[126]

A pre-modern agricultural solution to compensate for this leakage in the nitrogen circle, the use of grain legumes to fix atmospheric nitrogen, was used on smaller farms more than it was on larger ones, as several studies now show.[127] This ammonia-leakage therefore increased the differences between smaller and larger farms even more.

Most scholars consider nitrogen to be the most deficient element.[128] Newman and Harvey, however, find phosphorus to be the most deficient when they calculated the nutrient balances for the demesne of Merton College's manor of Cuxham, Oxfordshire for the 1320s and 1330s. They considered the demesne, 269 acres of arable, 29 acres of meadowland and 22 acres of

[126] Lamond (ed.), *Walter of Henley*, p. 19.

[127] Stone, *Decision-making*, pp. 265–6; Sapoznik, 'Productivity of peasant agriculture', pp. 518–44; La Poutré, 'Contribution of legumes', pp. 19–38.

[128] See, for example, Robert C. Allen, 'The nitrogen hypothesis and the English agricultural revolution: a biological analysis', *JEcH* 68 (2008), pp. 182–210.

pasture, as a 'black box' and tabulated what products entered and left the demesne, calculating for each of them the nitrogen-, phosphorus- and potassium-content.[129] The balance for nitrogen was indecisive. For phosphorus however they established a negative balance of 0.6–0.8 lb per acre per year. They estimate that, due to the weathering of rock material in the soil, some 0.04–0.4 lb of phosphorus became available per acre yearly, which was not enough to compensate the loss of this main nutrient.[130] Since they also found declining yields for wheat, they concluded that phosphorus might have been the deficient nutrient for Cuxham.[131] Given that this argument holds for large and small farms alike, peasants might not have been able to raise their yields above demesne ones, because the deficient nutrient determined the size of the yield. Because of the relevance to this study, this issue has to be addressed.

According to Newman and Harvey, Cuxham demesne had sufficient meadowland and made only limited use of pasture land. In these aspects it is comparable to the Midlands model. According to Table 2, a large part of the nutrients transported to arable land came from hay. Therefore, if Cuxham indeed had a phosphorus deficit, it must have been caused by exhausted meadowlands, due to years of removing nutrients. Unfortunately, however, the Cuxham study leaves some sources of phosphorus input out of the equation. Drifting sands, from heaths, dunes and deserts might have contributed to fertilization of arable and pasture soils alike. Based on measurements of the deposition of Saharan dust, Newman estimates the contribution to be some 0.3 lb of phosphorus per acre per year in Israel.[132] To arrive at such a figure, no more than 30 grams of sand on a square metre per year is needed. Besides this, the flooding of meadowland in winter must have brought phosphorus to these soils. Although it might have been far below the 3 lb per acre per year that Newman has calculated for the flooding of the Nile in ancient Egypt, it must have played an important role to keep the meadows fertile.[133] Another option, the spreading of the ashes of firewood, is mentioned in the Cuxham study, but is not incorporated in the calculation.[134] Marling, another way of adding phosphorus, is left out of the equation because it is not mentioned in the 14 accounts studied by Newman and Harvey. Furthermore, 'we should bear in mind that Cuxham had a high proportion of its area as cropland, it had a high yield of wheat, and a high proportion of that was exported'.[135] To be precise, 54 per cent of their crop yield left the demesne as tithe, as gift, was sent to Merton college in Oxford (who owned the manor), or was sold.[136] The combination of high amounts of grains leaving the manor and minimum use of pastures led to the found deficit on phosphorus. Such a combination is improbable to hold for the whole manor. Even when half-virgates were in a position to sell half their yield, most cottagers should have been forced to buy a great deal of their grains, since they were not able to achieve self-sufficiency.

129 Newman *et al.*, 'Did soil fertility decline', pp. 119–36.

130 Deficit: 0.70–0.94 kg/ha/yr. Release by weathering 0.05–0.5 kg/ha/yr; see Newman *et al.*, 'Did soil fertility decline', p. 131.

131 Ibid., pp. 119–36.

132 Newman, 'Phosphorus inputs to terrestrial ecosystems', *J. of Ecology,* 83 (1995), p. 721.

133 E. I. Newman, 'Phosphorus balance of contrasting farming systems, past and present. Can food production be sustainable?', *J. Applied Ecology,* 34 (1997), p. 1340; Newman *et al.*, 'Did soil fertility decline', p. 131.

134 Newman *et al.*, p. 132.

135 Ibid., p. 135.

136 Calculated from the figures (Table 4) in Newman *et al.*, p. 126.

Therefore it is questionable whether the phosphorus content of the soil did indeed decrease *c.*1300. Even if it did, it is improbable that phosphorus was the deficient nutrient, since grain yields around 1700 were much higher than medieval ones, although the use of fertilizers specifically aimed at raising the soil's phosphorus content, namely guano and phosphate rock, was still in the future.[137] What is more, the soil phosphorus content for a plough layer of about 0.2 m could be some 2500 lb per acre.[138] Even when a large part was not in an available form, the weathering process would have converted enough to sustain this kind of husbandry for hundreds of years.

Decreasing phosphorus concentrations therefore might not have been the most probable cause of declining yields. Perhaps declining labour input might have been the cause, as Stone found for Wisbech Manor.[139] A study of this relationship, however, falls outside the scope of this study.

VII

Even when lords made use of their privilege of the fold for the whole year, Table 3 shows that the average peasant acre received more manure than a seigneurial one. Most of this manure had to be carted to and spread on the arable, therefore requiring a lot of labour input. Most peasants, however, were not short of labour. As this study shows, they were not short of manure either. Most peasants were short of land. They must have tilled their land as intensively as they could, using all manure they had at their disposal. One may therefore assume that their yields were much higher than those on demesnes. Even where some peasants might have sold some of their manure to their lord, the amounts must have been small, because of the labour input necessary for carting and spreading. On the contrary, as noted above, it seems more plausible that demesnes might have left part of their farmyard manure unused. The difference between an average peasant acre and a seigneurial one therefore might have been even somewhat greater than Table 3 shows.

Although villein acres received less manure than freehold acres, our calculations show that an average non-demesne acre received well over 50 per cent more than a demesne acre. Keeping in mind that the lord's managers might have reduced exploitation costs by leaving part of the dung unused, differences between demesne and peasant land might have been even bigger. The results for the two model manors are comparable. Although the amounts of manure, deposited on arable land, are somewhat smaller on our East Anglian model manor, due to sheep dunging on pastures more frequently, for both models the non-demesne sector was much better manured than the seigneurial sector. Similar results for these two models give some confidence in the robustness of the modelling process. Apparently, differences between the husbandry systems of these two models led to minor differences in results. Although husbandry practises differed from manor to manor, one may have some confidence

137 For figures on yields, see: Broadberry *et al.*, *British economic growth*, p. 97.

138 The soil density is about 1400 kg/m^3. A 0.2 meter soil layer, with a P concentration of 1 mg/g, therefore contains $1400 \times 10{,}000 \times 0.2 \times 0.001 = 2800$ kg/ha. For the P concentration, see Newman, 'Phosphorus balance', p. 1339; Newman, 'Phosphorus inputs', p. 715.

139 Stone, *Decision-making*, pp. 39–40, 61–72.

that the results of this study hold for many manors in the Midlands and in the southern and eastern counties.

Fifty per cent extra manure, combined with more labour-intensive activities, like weeding, must have made possible much greater output. Given these results, a 50 per cent higher output seems quite probable. Such a theoretical prediction is consistent with the Sapoznik's study of Oakington. As mentioned before, her study shows 21 to 81 per cent higher output from peasant land. To arrive at these figures, she combines tithe records with estimates of the size of the tithed land. Since her approach is completely different from the one in this article, the consistency between Sapoznik's work and ours is encouraging. Whether this greater output is a result of higher yields per sown acre, or due to minimizing the proportion of land left fallow, as Sapoznik convincingly argues, cannot be clarified from the present analysis.[140] Both options put pressure on the maintenance of soil fertility. However, it seems quite plausible that the cultivation of legumes on the fallow of peasant land must have played an important role at manors with sufficient flexible field systems. Such an expectation is in line with Boserup's influential theory on the influence of population pressure on agricultural practise.[141]

A higher level of peasant output would solve the dilemma about the average holding size around 1300. As a result of population pressure, holding size was quite small, especially in south-eastern counties. If their output per arable acre was comparable to those of demesnes, most households would not have been able to make a living from it. They therefore must have had additional earnings through other forms of labour. Even Kitsikopoulos' model family, cultivating 18 arable acres, spent 80 man-days outside its own farm.[142] Unfortunately, scholars have not been able to find an outlet for such enormous amounts of labour. However, when peasant stocking densities were higher than those of demesnes, and peasant arable output per acre was higher too, as this study makes plausible, many more households were able to support themselves from the output of their holdings. The minimum needed for subsistence could shrink from 18 to some 12 arable acres, which would mean that more than half of the holdings in Kazanka's Hundred Rolls analysis were above threshold size.[143] Therefore, the problem of the missing additional labour becomes less severe.

Besides this, higher arable output of peasant lands has consequences for the maximum population number that is supported by England's total arable output. Of course the results from this article cannot be used to make an estimate of England's population size at its medieval peak. Especially the precise value of the multiplication factor, estimated in Section II, for the inverse relationship between farm size an stocking densities, probably varied from time to time and from region to region. Such a variation, though of minor importance to this study, prevents us from making any estimate.

However, the results from this study can be used to reconcile two different approaches in the population debate. Each approach is supported by an impressive amount of data. Based

[140] Sapoznik, 'The productivity of peasant agriculture', pp. 518–44.

[141] Ester Boserup, *The conditions of agricultural growth: the economics of agrarian change under population pressure* (1965).

[142] Kitsikopoulos, 'Standards of living', pp. 243–4, 255.

[143] Kanzaka, 'Villein rents', p. 599.

on mean demesne yields, Campbell states that the population number *c.*1300 must have been some 4.4 million.[144] Clark, using time series on farm wages and product prices, argues that it must have been some 6 million.[145] The result of this study, some 50 per cent higher output in the non-demesne sector, would raise Campbell's number towards 6 million.[146]

In conclusion, it appears that manorial demesnes, despite their size (or because of it) lacked animals. In turn they lacked manure. For this reason they were doomed to relative failure. In this light, attempts to secure the dung of tenants' animals through the foldcourse are more readily explicable. Overall, we follow other recent writers in turning received wisdom on its head. It was the peasant sector which was productive, and the demesne which, for the reasons we have outlined here, was the laggard. Hence estimates of demesne productivity should be taken as the minimum rather than maximum in assessments of English agricultural productivity *c.*1300.

Appendix:
1392 taxpayers of Blackbourne Hundred, subdivided in groups according to the total volume of grains (cereals + legumes) in their possession.

Grain in quarters	*n*[a]	*Average number of animals per taxpayer*			*Livestock units*[b]	*Livestock units per quarter of grain*[c]
		Horses and cattle	*sheep*	*swine*		
0–0.20	94	1.7	30.9	0.1	4.9	–
0.25–0.70	21	2.3	3.7	0.3	2.8	5.7
0.75–1.20	86	2.2	4.4	0.1	2.9	2.9
1.25–1.70	94	2.4	3.3	0.3	2.8	1.9
1.75–2.20	117	2.6	4.4	0.3	3.2	1.6
2.25–2.70	99	2.4	3.9	0.3	3.0	1.2
2.75–3.20	88	2.9	5.9	0.2	3.7	1.2
3.25–3.70	62	3.1	3.6	0.5	3.6	1.0
3.75–4.20	80	3.3	4.2	0.9	4.0	1.0
4.25–4.70	63	4.1	6.1	0.7	4.9	1.1
4.75–5.20	62	4.5	6.4	1.1	5.4	1.1
5.25–5.70	46	5.2	6.5	1.1	6.0	1.1
5.75–6.20	43	4.2	11.5	0.7	5.7	1.0
6.25–6.70	41	4.8	9.6	1.2	6.1	0.9

144 Campbell, *English seigniorial agriculture*, pp. 392–3; id., 'Agrarian problem', p. 11.

145 Gregory Clark, 'The long march of history: farm wages, population and economic growth, England 1209–1869', *EcHR* 60 (2007), pp. 97–9, 120.

146 According to Broadberry *et al.*, *British economic growth*, p. 82, the share of the non-demesne sector was 75 per cent. Setting the demesne yield per acre to 100 per cent, the mean yield per acre was (25 × 100 + 75 × 150)/100 = 137.5%. Therefore the total population could have been 37.5 per cent above Campbell's value.

Appendix *continued*

Grain in quarters	*n*[a]	*Average number of animals per taxpayer*			*Livestock units*[b]	*Livestock units per quarter of grain*[c]
		Horses and cattle	*sheep*	*swine*		
6.75–7.20	43	5.7	12.2	0.7	7.3	1.0
7.25–7.70	33	5.5	10.4	2.2	6.9	0.9
7.75–8.20	38	6.2	12.6	1.7	7.9	1.0
8.25–8.70	20	7.1	13.6	3.2	8.8	1.0
8.75–9.20	17	6.3	12.0	2.9	8.2	0.9
9.25–9.70	17	6.4	12.0	2.3	8.1	0.9
9.75–10.20	19	6.2	37.4	1.5	10.2	1.0
10.25–10.70	12	6.6	9.0	1.0	7.7	0.7
10.75–11.20	18	5.7	12.8	1.6	7.4	0.7
11.25–11.70	14	8.6	13.3	4.0	10.6	0.9
11.75–12.20	10	7.2	12.2	1.1	8.9	0.7
12.25–12.70	8	7.8	21.8	1.4	10.6	0.9
12.75–13.20	10	7.2	40.6	2.0	12.1	0.9
13.25–14.20	19	6.9	25.2	4.2	10.2	0.7
14.25–16.20	18	9.4	24.4	2.9	12.5	0.8
16.25–20.20	23	10.3	29.3	4.2	13.9	0.8
20.25–24.20	17	10.9	37.6	5.1	15.7	0.7
24.25–28.20	21	13.7	42.3	8.9	19.8	0.8
28.25–46.20	19	13.1	79.1	8.2	22.5	0.6
46.25–236.00	20	28.7	46.2	24.8	36.8	0.4

Notes:
[a] Number of taxpayers in this group.
[b] Livestock Units, according to the weighting scheme of Overton & Campbell: Horses × 1, cattle × 1.2, immature cattle × 0.8, sheep × 0.1, swine × 0.1.
[c] Total number of Livestock Units in each category, divided by the total amount of grain in the category.
Source: calculated from the quantities mentioned in the tax list of Blackbourne Hundred in Edgar Powell, *A Suffolk Hundred in the year 1283* (1910).