

# Medieval sheep-corn farming: how much grain yield could each sheep support?\*

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## Abstract

In medieval times sheep were commonly grazed on pasture land by day but folded on arable each night. This was recognized as a way of improving the soil fertility of the arable. This paper calculates how much nitrogen, phosphorus and potassium per sheep would be transported to the arable by this practice, and hence how much grain export from the farm could be supported without soil fertility declining. The answer it is suggested, is about 3–5 bushels of grain per year per sheep. Applying these figures to data from demesne accounts of the thirteenth and fourteenth centuries shows that on some demesnes the number of sheep was fully adequate to maintain soil fertility, but on others it fell short.

There has been interest among historians in the suggestion that during some periods of the Middle Ages the fertility of farm soils was declining, leading to deteriorating yields of crops and, in some years, to starvation.<sup>1</sup> One cause of decline in the fertility of soil is a decline in its nutrient status. Mineral nutrients are taken up by crop plants and thus are removed from the field at harvest. If this removal is not balanced by an equal input, the fertility of the soil will decline. One way that nutrients can be added to arable soil is in animal manure. The role of manure in maintaining crop yields has frequently been discussed by historians.<sup>2</sup> Postan proposed that by the late thirteenth or early fourteenth century 'in corn-growing parts of the country taken as a whole, pasture and the animal population had been reduced to a level incompatible with the conduct of mixed farming itself'.<sup>3</sup> He did not say what animal population would be adequate to support mixed farming. Medieval records report that people carted and spread dung; sometimes they were fined for collecting it when they should not. As Dyer succinctly put it: 'Peasants certainly appreciated the value of manure, which was bought, sold,

\* I thank Professors B. M. S. Campbell, C. Dyer and J. Langdon for helpful suggestions and information.

<sup>1</sup> W. Denton, *England in the fifteenth century* (1888), pp. 153–6; M. M. Postan, *The medieval economy and society* (1972), pp. 67–79; M. M. Postan, *Essays on medieval agriculture and general problems of the medieval economy* (1973), pp. 15, 172; C. Dyer, *Standards of living in the later Middle Ages* (1989), pp. 5–6; B. F. Harvey, 'Introduction: the "crisis" of the early fourteenth century', in B. M. S. Campbell (ed.), *Before the Black Death* (1991), pp. 1–24; B. M. S. Campbell, *English seigniorial agriculture, 1250–1450* (2000), pp. 16–19.

<sup>2</sup> J. A. Raftis, in H. E. Hallam (ed.), *The Agrarian History*

*of England and Wales*, II, 1042–1350 (1988) (hereafter *Agrarian History*, II), p. 338; C. Dyer, in *Agrarian History* II, p. 377; P. D. A. Harvey, in E. Miller (ed.), *The agrarian history of England and Wales*, III, 1348–1500 (1991) (hereafter *Agrarian History*, III), p. 263; E. Miller, in *Agrarian History*, III, pp. 285, 290; Dyer, *Standards of living*, pp. 127–8, 143; C. Thornton, 'The determinants of land productivity on the Bishop of Winchester's demesne of Rimpleton, 1208 to 1403', in B. M. S. Campbell and M. Overton (eds), *Land, Labour and Livestock* (1991), pp. 183–210.

<sup>3</sup> Postan, *Medieval economy*, p. 65.

borrowed and stolen'.<sup>4</sup> This paper concentrates on another method that was used to apply faeces and urine to arable: the practice of folding sheep there at night. It starts from the assumption that the folding of sheep could supply enough nutrients to support a certain grain production and export (per animal) without the nutrient status of the soil declining. It uses scientific information to estimate how much grain could be grown from the dung and urine of a typical sheep. It then goes on to apply this estimate to a number of well-documented medieval farms to establish whether or not they had enough sheep to maintain their crop yields in the long term.

# I

All plants, including crop plants, require certain essential mineral nutrient elements in order to grow. This paper will concentrate on three elements, nitrogen (N), phosphorus (P) and potassium (K), the three that are most often limiting to modern crops in Britain if artificial fertilizer is not applied. Cereal plants must obtain these from the soil. Leguminous crops such as peas and beans can obtain N from the air, with the help of bacteria in their roots, but their P and K must come from the soil. When a crop is harvested, some of the N, P and K taken up is removed in the seed and straw. In medieval times some of the nutrients in seeds were returned to the soil, e.g. in seeds sown the following year, and in manure from farm animals that had been fed on grain. All the nutrients in straw were returned to the soil. However, some of the nutrients were exported from the farm, e.g. in grain sold or sent to an absentee owner.

The sheep-fold system, which was widespread in medieval times, involved the sheep grazing by day on pasture land, but being folded each night on arable stubble or ploughed fallow. The value of this practice for contributing to soil fertility was recognized in medieval times, as shown by regulations governing it, and sometimes payments for it, as well as contemporary instructions to let the sheep 'donge and pysse' on the fold.<sup>5</sup> The food which sheep ate during the day in the pasture land contained mineral nutrients which the pasture plants had taken up from the soil. At night the sheep's faeces and urine deposited on the arable some of the nutrients they had eaten in the pasture. The sheep were thus acting as transporters of nutrients to the arable. If the sheep are adults, and not producing milk, virtually all of the nutrients in their food must come out in the faeces and urine. In fact, almost all the P is in the faeces and scarcely any in their urine, whereas N and K are lost in both urine and faeces.<sup>6</sup> The first aim of this paper is to calculate how much N, P and K an average medieval sheep transported per day from the pasture to the arable. It thus emphasizes input to the arable: the calculations do not include return of nutrients that had been taken from the arable, for example in dung from animals

<sup>4</sup> P. D. A. Harvey, *A medieval Oxfordshire village: Cuxham, 1240 to 1400* (1965), p. 83; N. S. B. Gras and E. C. Gras, *The economic and social history of an English village* (1930), pp. 47, 206; Dyer in *Agrarian History*, III, p. 232.

<sup>5</sup> E. Kerridge, 'The sheepfold in Wiltshire and the floating of the watermeadows', *EcHR* 6 (1954), pp. 282-9; E. Kerridge, *The common fields of England* (1992), pp. 74-86; P. F. Brandon, 'Demesne arable farming in coastal Sussex during the later middle ages', *AgHR* 19 (1971),

p. 130; J. N. Pretty, 'Sustainable agriculture in the middle ages: the English manor', *AgHR* 38 (1990), pp. 1-19; Dyer, in *Agrarian History*, II, p. 377; Sir Anthony Fitzherbert (attrib.) *The book of husbandry*, ed. W. W. Skeat, *English Dialect Soc.* 37 (1882), p. 28.

<sup>6</sup> N. J. Barrow and L. J. Lambourne, 'Partition of excreted nitrogen, sulphur and phosphorus between the faeces and urine of sheep being fed pasture', *Australian J. of Agricultural Research* 13 (1962), pp. 461-71.

housed on straw and fed on grain. The paper then calculates how much grain would contain the amount of N, P and K transported per sheep per year; that is the amount of grain production and export that folding one sheep could support.

Among the few published attempts to calculate nutrient balances for historic farms was that by Newman and Harvey for the medieval demesne at Cuxham (Oxfordshire).<sup>7</sup> It had few animals; they were included in calculations of nutrients exported from the farm, but no calculations were made of transport within the farm. Dodgshon and Olsson have made calculations of N and P cycling on eighteenth-century farms in the Scottish Highlands and in southern Sweden, which involved animal manure.<sup>8</sup> At the Scottish sites nightly folding of animals occurred only in summer, and only on the outfield. The infield received manure from cattle housed in winter, from animals grazed on stubble and from human excreta. In the results these manure inputs are not separated, so transport to the arable is not separated from recycling within it. Sheep manure was only a small proportion of it. The N and P in this total manure was sufficient to balance the amount in grain harvested at three of the sites but not at two others. There were other nutrient inputs to the arable, including in turf applied. The calculations for southern Sweden show that two farms that had access to hay meadows and extensive pasture had an N and P input to their arable that was more than sufficient to balance N and P harvested in the crops; but a village with less meadow, little pasture and fewer animals had an N and P input to arable which was less than was in the crops. Unfortunately, little information is given about the calculations. The text implies that the manure came only from cattle when housed in winter: although there were also sheep, horses and pigs, the possible contribution of their manure is not mentioned.

There have been calculations of the number of sheep per arable acre, or of 'animal units' per 100 arable acres, where sheep, cattle and horses contribute units according to their size.<sup>9</sup> The assumption is that the higher the ratio the more manure per acre. That may well be true, although some of the manure would probably fall on pasture or elsewhere. These calculations, do not, however, form the basis for determining what value of the ratio is sufficient to prevent soil fertility declining.

There appear to be no previous calculations with the same aim as the present paper. It therefore starts afresh, using scientific information about sheep and data on medieval farming practices.

## II

The first step is to calculate how much N, P and K would be transported from pasture to fold by one average medieval sheep in a year. In order to calculate that transport, we need to answer the following questions.

- (i) How much N, P and K are contained in the urine and faeces that a sheep deposits over 24 hours?

<sup>7</sup> E. I. Newman and P. D. A. Harvey, 'Did soil fertility decline in medieval English farms? Evidence from Cuxham, Oxfordshire, 1320-1340', *AgHR* 45 (1997), pp. 119-136.

<sup>8</sup> R. A. Dodgshon and E. G. Olsson, 'Productivity and nutrient use in eighteenth-century Scottish townships',

*Geografiska Annaler* 70B (1988), pp. 39-51; R. A. Dodgshon, 'The ecological basis of highland peasant farming, 1500-1800 AD' and G. Olsson, 'Nutrient use and productivity for different cropping systems in south Sweden during the eighteenth century', both in H. H. Birks (ed.), *The cultural landscape: past, present and future* (1988).

- (ii) How long does material take to pass through a sheep, from the time it is eaten until it appears as faeces and urine? If this time is short, say an hour, then most nutrients deposited will come from nearby, so the sheep will be ineffective transporters.
- (iii) How is the grazing activity of sheep distributed through the day? Do they eat mainly during daylight or also at night (and if so how much)?
- (iv) Similarly, how is their defecation and urination activity distributed through the day?

The information to answer these questions will necessarily come from twentieth-century investigations, but we should also consider whether any adjustments to the figures will be needed to make them apply to medieval sheep, to allow, for example, for any difference in size or management.

(i) *Nutrients excreted per sheep per day*

A problem in finding suitable data is that nowadays almost all pasture land in lowland England has been improved, meaning it has been sown with modern grass varieties and receives generous amounts of fertilizer. The closest to medieval pasture, in soil conditions, vegetation type and nutrient contents are to be found in upland areas. Suitable measurements have been made of sheep grazed on pasture part way up Mount Snowdon in North Wales.<sup>10</sup> Although the site is 490m above sea level, the soil and pasture vegetation are similar to old, unimproved pastures in lowland England. The sheep were on the hillside from May to October. Over this period, the amounts of nutrients deposited in dung plus urine were: 28.3g N, 2.48g P and 22.6g K per adult sheep per day.

To check whether the Snowdon site and sheep were fairly typical, the most useful comparison we can make, with existing data, is the amount they ate per day. If they eat more they will take in more nutrients and will excrete more. The Snowdon sheep ate on average 1.3 kg per adult sheep per day (weight of plant material after drying). In four studies in Scotland the amount eaten ranged from 0.7 to 1.8 kg per day.<sup>11</sup> In three studies at lowland sites with improved grassland 1.0 to 1.6 kg per day was eaten, though a fourth study found higher values.<sup>12</sup> So the Snowdon sheep were near the centre of the reported range. The other studies mostly involved sheep that were larger than at Snowdon. The relevance of sheep size is considered later.

<sup>9</sup> J. Z. Titow, *Winchester yields* (1972), Table L; Campbell, *English Seigniorial agriculture*, pp. 104–5; B. Harrison, 'Field systems and demesne farming on the Wiltshire estates of Saint Swithuns' Priory, Winchester, 1248–1340', *AgHR* 43 (1995), p. 16.

<sup>10</sup> O. W. Heal and D. F. Perkins, *Production ecology of British moors and montane grasslands* (1978), pp. 348–95.

<sup>11</sup> J. A. Milne, L. Bagley and S. A. Grant, 'Effects of season and level of grazing on the utilization of heather by sheep', *Grass and Forage Science* 34 (1979), pp. 45–53; J. Hodgson *et al.*, 'Comparative studies of the ingestive behaviour of sheep and cattle', *J. Applied Ecology* 28 (1991), pp. 205–27; P. M. Haygarth *et al.*, 'Phosphorus budgets for two contrasting grassland farming systems in the UK', *Soil Use and Management* 14 (1998), pp. 160–67; G. R. Iason, D. A. Sim and I. J. Gordon, 'Do endogenous

seasonal cycles of food intake influence foraging behaviour and intake by grazing sheep?', *Functional Ecology* 14 (2000), pp. 614–22.

<sup>12</sup> W. S. Jamieson and J. Hodgson, 'The effects of variation in sward characteristics upon the ingestive behaviour and herbage intake of calves and lambs', *Grass Forage Science* 34 (1979), pp. 273–82; A. J. Parsons *et al.*, 'The physiology of grass production under grazing', *J. Applied Ecology* 20 (1983), pp. 127–39; P. D. Penning, A. J. Rook and R. J. Orr, 'Patterns of ingestive behaviour of sheep continuously stocked on monocultures of ryegrass or white clover', *Applied Animal Behaviour Science* 31 (1991), pp. 237–250; A. J. Parsons *et al.*, 'Uptake, cycling and fate of nitrogen in grass-clover swards continuously grazed by sheep', *J. Agricultural Science* 116 (1991), pp. 47–61.

This paper assumes that all the nutrients passing into an adult sheep in its food must emerge again later in its faeces and urine. This must be true if the sheep is neither growing nor lactating. However, adult sheep may gain weight, or may lose weight at other times of the year if their food supply is inadequate. In the Snowdon study the adult sheep increased in weight quite substantially during the summer. The proportion of their nutrient intake that was retained in their bodies was: N, 4.0 per cent, P, 12.0 per cent and K, 0.3 per cent. For most of the calculations which follow, these are small enough 'errors' to be ignored, but we should bear in mind that P transport may be somewhat overestimated.

If we want to use the nutrient excretion rate per day, determined from May to October, to calculate the total for the year, we need to know whether sheep eat and excrete less in winter. Sheep eat for about the same number of hours per day in all seasons of the year.<sup>13</sup> However, if there is poor vegetation growth in winter they might acquire less. I have found data on how intake by sheep changes through the months May to November, but unfortunately not through the whole year.<sup>14</sup> On the basis of these data the calculations assume that intake for December to February is 60 per cent of the rate in May to July, with other months intermediate. So the average rate over a whole year would be about 20 per cent less than in summer. As an independent check of that, multiplying the Snowdon daily amount of P excreted during May–July by 365 gives a yearly rate of 0.97 kg excreted per sheep, whereas calculations for a Scottish hill farm gave 0.75 kg per sheep for a whole year, 23 per cent less.<sup>15</sup>

(ii) *How long do nutrients take to pass through a sheep?*

This question has been investigated by mixing into sheep's food a marker, such as a dye, radioactive material or fine particles, and finding out how much of it is contained in faeces produced at intervals over the next few days. The marker commonly begins to appear in the faeces within 24 hours, but then continues to be found over 5 to 10 days. The time for half of the marker to pass through the sheep ('mean retention time') varied among different experiments from 31 to 107 hours.<sup>16</sup> Marker elements appear in urine sooner than in faeces, but they continue to appear in the urine for several days.<sup>17</sup> So faeces and urine dropped at one time contain materials that were in food taken in over several days. This time scale is long enough for transferring sheep from pasture to fold every night to be potentially an efficient method of transporting nutrients from one to the other. If, in contrast, sheep were left on the fallow

<sup>13</sup> D. E. Tribe, 'Some seasonal observations on the grazing habits of sheep', *Empire J. Experimental Agriculture* 17 (1949), pp. 105–115; G. P. Hughes and D. Reid, 'Studies on the behaviour of cattle and sheep in relation to the utilization of grass', *J. Agricultural Science* 41 (1951), pp. 350–66.

<sup>14</sup> Milne *et al.*, 'Seasonal grazing'; Hodgson *et al.*, 'Ingestive behaviour'; Parsons *et al.*, 'Uptake'; Iason *et al.*, 'Seasonal cycles'.

<sup>15</sup> Haygarth *et al.*, 'Phosphorus'.

<sup>16</sup> W. L. Grovum and V. J. Williams, 'Rate of passage of digesta in sheep', *British J. Nutrition* 30 (1973), pp. 313–329;

A. C. I. Warner, 'Rate of passage of digesta through the gut of mammals and birds', *Nutrition Abstracts and Reviews*, Ser. B, 51 (1981), pp. 789–820; M. Kaske and W. von Engelhardt, 'The effect of size and density on mean retention time of particles in the gastro intestinal tract of sheep', *British J. Nutrition* 63 (1990), pp. 457–65.

<sup>17</sup> A. M. Downes and I. W. McDonald, 'The chromium-51 complex of ethylene diamine tetraacetic acid as a soluble rumen marker', *British J. Nutrition* 18 (1964), pp. 153–162; K. Krawielitzki *et al.*, 'Nitrogen secretion and absorption in different segments of the digestive tract', *J. Animal and Feed Sciences* 8 (1999), pp. 129–43.

continuously for ten days or longer, by the end much of the material in the faeces and urine would be from what the sheep ate earlier on the fallow.

(iii) *How is grazing activity distributed through the day?*

Whether sheep graze during darkness, and if so for how long, has been investigated by direct observation, using moonlight, dim artificial light or short bursts of bright light; or by a device which can be attached to the sheep to record its jaw movements. Three studies in different parts of Britain all showed that during summer sheep ate scarcely at all during darkness. However, as the days got shorter in autumn, the sheep ate more during darkness. Observations through a whole year, in Warwickshire, found that from May to August 96 per cent of the sheep's grazing time was during daylight, only 4 per cent in darkness; whereas in December 41 per cent was in darkness. The figures for other months were intermediate. More limited observations in Berkshire gave similar results.<sup>18</sup>

(iv) *How is defecation and urination activity distributed through the day?*

It is well known that sheep do defecate at night as well as by day: wherever they spend the night they leave droppings. What we want to know is, do they deposit as much urine and faeces per hour by night as they do by day? Information on this is unfortunately limited, and I have found none for Britain. The most directly relevant is from Syria; the climate is cool and wet in winter but hot and dry in summer, so information from April and May, while the weather was not yet very hot and dry, and when the sheep were grazing green pasture, is used here. The sheep were on the pasture for about nine hours per day; the rest of the 24 hours they were held in a yard. The amount of faeces deposited in the yard was a little less than that in the pasture, but allowing for the longer time in the yard, the rate of deposition per hour in the yard was only 47 per cent of that in the pasture. For urine deposition the figure was 54 per cent. However, nitrogen deposition in excreta in the yard, per hour, was 62 per cent of that in the pasture, because the excreta were usually more concentrated at night.<sup>19</sup>

Another source of information is from a study conducted in New South Wales, Australia, in November, when temperatures were similar to English summer.<sup>20</sup> Sheep were free to move within a paddock throughout each 24 hours, but they were observed to spend most of the darkness resting in one small area, and daylight moving about in the remainder of the paddock. Faeces collected from these areas showed that deposition of faeces per hour during the night (10 hours) was, on average, 81 per cent as fast as during daylight. Urine production was not measured. Collection of faeces at another site in New South Wales and urine in Finland, throughout a few 24-hour periods, showed little variation of production rate through the 24 hours.<sup>21</sup>

<sup>18</sup> Tribe, 'Seasonal observations'; Hughes and Reid, 'Behaviour'; Penning *et al.*, 'Patterns'.

<sup>19</sup> P. F. White, T. T. Treacher and A. Termanini, 'Nitrogen cycling in semi-arid Mediterranean zones: removal and return of nitrogen to pastures by grazing sheep', *Australian J. Agricultural Research* 48 (1997), pp. 317-22.

<sup>20</sup> J. A. Taylor *et al.*, 'Camping and faeces distribution

by merino sheep', *Applied Animal Behavioural Science* 17 (1987), pp. 273-88.

<sup>21</sup> J. L. Corbett and F. S. Pickering, 'Estimation of daily flows of digesta in grazing sheep', *Australian J. Agricultural Research* 34 (1983), pp. 193-210; M. Valtonen, J. T. Laitinen and L. Eriksson, 'Renal melatonin excretion in sheep is enhanced by water diuresis', *J. Endocrinology* 138 (1993), pp. 445-50.

Thus the rate of excreta production during darkness can vary from being about equal to the rate in daylight, down to only about half as fast. The calculations take excretion per hour in darkness to be 75 per cent of the rate during daylight.

### III

So far, all the information has been from twentieth-century sheep. Applying them to medieval sheep raises several questions:

- (i) How much of the day did sheep spend in the fold?
- (ii) Would they eat less at night than twentieth-century observations suggest, because the fold offered little for them to eat?
- (iii) Were medieval sheep smaller than those which provided the figures for amount of N, P and K excreted? If so, they might eat and excrete less per day.

To consider the first question: how early did the shepherd take the sheep out to pasture: in the first glimmerings of light before dawn, at sunrise, or later? And when did they return to the fold in the evening? Although some detailed regulations about folding are known to have existed, I can find no indication that they covered this matter. The anonymous *Seneschaucie* said that the shepherd and his dog ought to sleep in the fold. This might encourage him to rise early. However, Fitzherbert recommended 'in the mornynge, whan he [the shepherd] cometh to his folde, let not his shepe out anone ... let them stand styлле good season, that they may donge and pysse'. And later he says that it may be best to wait until the grass has dried before letting the sheep out of the fold.<sup>22</sup>

The information on how much twentieth-century sheep ate at night applies where the sheep were in the same pasture area throughout the 24 hours. Would they eat as much at night if they were on the fold? They were usually crowded into a fairly small fold. Beneath their feet was mainly bare ground or stubble, although sometimes they had access to a grassy baulk, or to weeds. Walter of Henley thought they ate little there: 'They are driven for the night in the fold, and by chance the morrow also ... and then come to the manger starving'.<sup>23</sup> Modern sheep, if kept on stubble continuously for several weeks, lose weight.<sup>24</sup> Stubble, as well as being unpalatable, has much lower nutrient concentration than pasture vegetation (see Table 1). There are therefore two opposing adjustments to be made to the amount eaten on the fold. First, the sheep may have spent more time there than the length of night assumed above when determining how much sheep eat at night. But secondly there was little palatable forage, or of high nutrient content, in the fold. In the calculations greater weight is given to the second of these; the amount eaten in the fold each month is taken as half the amount of night-time eating observed during the twentieth century. For calculating amount of faeces and urine dropped on the fold, it is assumed that the sheep were there from sunset to sunrise, with daylength as in the English midlands.

<sup>22</sup> E. Lamond (ed.), *Walter of Henley's Husbandry, together with an anonymous Husbandry, Seneschaucie and Robert Grosseteste's Rule* (1890), p. 115; Fitzherbert, *Husbandry*, pp. 28, 51.

<sup>23</sup> *Ibid.*, p. 31.

<sup>24</sup> J. B. Coombe, A. Axelsen and H. Dove, 'Rape and sunflower seed meals as supplements for sheep grazing cereal stubbles', *Australian J. Experimental Agriculture* 27 (1987), pp. 513-23.

TABLE 1. Concentration of nitrogen (N), phosphorus (P) and potassium (K) in grain and other farm materials. Data from late nineteenth- and twentieth-century measurements, mostly from plants grown without inorganic fertilizer. Units: mg per g dry matter.

	Concentration (mg/g)		
	N	P	K
Grain			
wheat, oats <sup>a</sup>	18.0	3.6	4.8
barley <sup>a</sup>	14.0	3.1	5.2
rye <sup>b</sup>	14.0	3.1	4.1
peas <sup>a</sup>	40.0	4.0	10.0
beans <sup>a</sup>	43.0	4.0	10.0
Straw <sup>c</sup>	4.0	0.9	8.0
Pasture herbage <sup>d</sup>	23.0	2.1	17.0
Hay <sup>a</sup>	18.0	1.4	14.0

Sources:

<sup>a</sup> Newman and Harvey, 'Soil fertility', Table 5.

<sup>b</sup> B. Holland *et al.* (eds), *McCance & Widdowson's Composition of Foods* (1991); J. Ellen, 'Growth, yield and composition of four winter cereals', *Netherlands J. Agricultural Science* 41 (1993), pp. 235-246; F. Selles, C. A. Campbell and R. P. Zentner, 'Effect of cropping and fertilization on plant and soil phosphorus', *Soil Science Society of America J.* 59 (1995), pp. 140-144.

<sup>c</sup> A. E. Johnston, 'The plant nutrients in crops grown on Broadbalk', *Rothamsted Annual Report for 1968* (1969), part 2, pp. 50-62; G. V. Dyke *et al.*, 'The Broadbalk wheat experiment, 1968-78', *Rothamsted Annual Report for 1982* (1983), part 2, pp. 5-44.

<sup>d</sup> Heal & Perkins, *Production*.

Concerning sheep size, it is the size of the body or the total weight of the animal that is relevant. There seem to be no written medieval records of this. There are numerous records of wool weight per sheep, but that depends on the length of the wool as well as the size of the fleece. Some evidence comes from the size of parchment made from sheepskin, though the largest animals may have been preferred for that. Medieval pictures and brasses show the appearance of sheep, though often without a clear scale. The most extensive quantitative information on the size of medieval sheep is from their bones. Large quantities of bone have been recovered from sites where there were waste tips from medieval dwellings or butchers, and lengths and widths of numerous leg bones have been measured. The body weight supported may be better indicated by the width of leg bones than by their length. All these sources of evidence have been used to compare medieval sheep with breeds still extant. The commonest conclusion has been that adult medieval English sheep weighed about 30kg, although 20 and 35kg have also been suggested.<sup>25</sup> In the Snowdon study which provided the figures for N, P and

<sup>25</sup> P. L. Armitage and J. A. Goodall, 'Medieval horned and polled sheep: the archaeological and iconographic evidence', *Antiquaries J.* 57 (1977), pp. 73-89; M. Maltby, *The animal bones from Exeter* (1979), pp. 48-54; T. O'Connor, *Animal bones from Flaxengate, Lincoln, c. 870-1500* (1982), pp. 23-32; M. L. Ryder, *Sheep and man* (1983), pp. 458-77; A. J. S. Gibson, 'The size and weight of cattle and sheep in early modern Scotland', *AgHR* 36 (1988), pp. 162-171; G. Clark, 'Labour productivity in English agriculture, 1300-1860', in Campbell and Overton (eds), *Land, Labour and Livestock*, pp. 214-7.



TABLE 2. Calculation of amount of nitrogen (N) transported from pasture to fold during October

N eaten and excreted per 24 hours during summer (Snowdon sheep)	28.3g/sheep/day
Food intake October (per cent of summer rate)	85.5%
N in food intake October ( $= 28.3 \times 0.855$ )	24.20g/sheep/day
Length of darkness	13.33 hours
N excreted during darkness <sup>a</sup>	11.71g/sheep/day
Percentage of 24-hour grazing activity in fold	9.5%
N intake from fold ( $= 24.2 \times 0.095$ )	2.30g/sheep/day
N transported ( $= 11.71 - 2.30$ )	9.41g/sheep/day

Note: <sup>a</sup> Calculated as follows:

Total N excreted = N excreted during daylight + N excreted during darkness =  $E(24-D) + 0.75ED$

where D = length of darkness (hours); E = excretion rate per hour during daylight; 0.75E = excretion rate per hour during darkness.

K in excreta the sheep were small by modern standards: they weighed 23–32kg. Therefore it seems appropriate to use the amounts they excreted, without adjustment, as the estimates of excretion by medieval sheep.

#### IV

We are now in a position to calculate the amount of N, P and K that a sheep would transport from pasture to fold, if it was on the pasture by day and in the fold at night. Not all the nutrients in the faeces and urine deposited on the fold were transported there: some came from food eaten there. The net amount of N transported is given by:

N in faeces and urine deposited in the fold – N in food eaten in the fold

The calculations have been performed separately for each month. Table 2 gives the calculations for N for one month as an example. The other nutrients and other months were calculated in the same way. Nutrient transport per day did not vary greatly through the year: during winter sheep spent more time in the fold per 24 hours, and so did more of their excretion there, but this was offset by a greater proportion of their daily eating being there, and their total daily excretion being less.

The transport of each nutrient per day for each month has been calculated, then summed over the whole year. The yearly transport (kg per sheep per year) was: N 2.89, P 0.254, K 2.31.

These calculations assumed that the movement from pasture to fold and back again occurred every day of the year. However, there were sheep houses in the Middle Ages; they were mentioned by contemporary writers and charges for mending them are recorded in accounts.<sup>26</sup> Sheep were presumably put there in winter, but there is some evidence that they were indoors only in bad weather. There was concern about sheep-rot if they were pastured

<sup>26</sup> Lamond (ed.), *Walter of Henley's Husbandry*, pp. 31, 99; Harvey in *Agrarian History*, III, pp. 265–6; H. E. J. Le Patourel in *Agrarian History*, III, pp. 878–880; R. Trow-Smith, *A history of British livestock husbandry to 1700* (1957), pp. 113–4; G. E. Fussell, *Farming techniques from prehistoric to modern times* (1966), p. 76.

on wet soil.<sup>27</sup> Walter of Henley wrote 'See that your sheep are in houses between Martinmas and Easter', but went on 'I say not if the weather be dry and the fold be prepared properly'; and later he specially mentions 'if wethers be in the house for a storm'. Fitzherbert wrote 'that man, that hath the best shepe-pasture for wynter ... may suffer his rammes to goo with his ewes all tymes of the yere'.<sup>28</sup>

If the sheep were indoors for some of the winter, how would this affect the nutrient transport to the arable? That depends on what feed the indoor sheep were given. In winter sheep were fed on hay, oats, peas and/or vetches.<sup>29</sup> If they were fed on hay, and their excreta were later spread on arable fields, that would result in nutrients being transported from the hay meadow to the arable, an input to the arable. But oats, peas and vetch were all grown on the arable, so if sheep were fed on them the nutrients in the excreta would not be an input to the arable, merely recycling back to it what the oats and legumes had taken out. How much hay was in the winter feed could thus make a difference to the annual nutrient balance. To illustrate this, suppose that the sheep were indoors on half of the days during the period recommended by Walter of Henley, 16 November to (say) 31 March. Suppose then that they were fed then only on hay, and all their excreta were taken out and spread on the arable fields. Suppose also that when indoors the sheep ate the same quantity of food as when grazing outdoors in the same months, but it had the NPK concentrations as given for hay in Table 1 (so a bit lower than in pasture herbage). Then we can calculate how this would alter the total amount of nutrients transported to the arable, compared with the sheep being outdoors all year. The amount of P transported per year would be increased by 12 per cent, N by 18 per cent and K by 19 per cent. On the other hand, suppose the sheep when indoors were fed oats, peas and vetch, but no hay. Then the only nutrient transport to the arable for those winter months would be on the days when the sheep were outdoors, and the total N, P and K transport to the arable over the whole year would be 18 per cent less than if the sheep had been outdoors all the time. If the sheep were fed a mixture of hay, oats and legumes, the effect on the nutrient balance would be intermediate, in other words less change from the figures for sheep outdoors all year. In the following calculations the median assumption is adopted, namely that the nutrient transport was the same as if the sheep had been outdoors all year.

In order to calculate how much grain production these transported nutrients would support, we need to know the concentrations of N, P and K in the grain. Table 1 shows relevant data. The cereals differ only slightly between species, but the legumes are higher in N and K.

Table 3 shows, as an example, the calculation of how much wheat could be supported by one sheep. If 161kg of wheat is harvested that removes in the grain 2893g of nitrogen. So if none of that N is returned to the soil, to maintain the N status of the soil that much N must be supplied, in this case by a sheep. The table shows that of the three elements, the P input by one sheep supports the least grain and K input the most. The reason for this can be seen by comparing the concentrations of the elements in grain and in pasture herbage, given in Table 2. Pasture herbage, which is mainly leaves, contains a higher concentration of N and K

<sup>27</sup> Kerridge, *Common fields*, p. 78.

<sup>28</sup> Fitzherbert, *Husbandry*, p. 42.

<sup>29</sup> Ryder, *Sheep and man*, p. 447; Trow-Smith, *British*

*livestock*, p. 158; Dyer in *Agrarian History III*, p. 235; Miller in *Agrarian History, III*, p. 297.

TABLE 3. Calculation of wheat production that could be supported by nutrients transported by one sheep in one year.

	N	P	K
Concentration in wheat grain (g/kg)	18.0	3.6	4.8
Nutrients transported (g/sheep/year)	2893.0	254.0	2310.0
Weight of grain (kg) containing that amount of the nutrient	161.0	71.0	481.0

than in cereal seeds, but a lower concentration of P. Excreta (urine plus faeces) of sheep will have a ratio of N:P:K similar to that in their food. So if a quantity of faeces plus urine contains just enough P to support 1kg of cereal, it will contain more than enough N and K to support 1kg. Comparing pasture herbage with legume seeds, the herbage is lower in N and P; but since legumes have their own extra source of N from the air, P will again be the element in shortest supply. So P will be the limiting element for cereal and legume production, long-term, if the main input of nutrients is from excreta of animals fed on pasture or hay.

It follows that we now need to calculate in more detail how much grain production the P transported by one sheep would support. Table 4 summarizes this. The production in bushels differs between crop species, partly because some require more P per kg than others, but also because of the differing weights per bushel. The prediction is that folding of one sheep over a year would supply enough nutrients to support about 3-5 bushels of grain.

## V

The figures in Table 4 can now be applied to individual medieval farms to calculate whether each one had enough sheep to support the amount of grain it exported. Because sheep are viewed here as transporters of nutrients to the arable from elsewhere, we are concerned not with how much grain the farm produced in total but with how much it exported. For example, if oats were fed to horses, whose manure was then spread on arable fields, that was not a loss of nutrients. But if oats were sold to outsiders, that was a nutrient loss. Straw does not feature in the calculations because all the nutrients in the straw were returned, in due course, to the arable. Some straw rotted in situ after the harvest; some was eaten by animals and the nutrients returned in their excreta; some was used as bedding and so became part of the manure spread on fields. Thatch would retain straw for longer, but not for ever.

So the information required about a farm is how much produce it exported, and also how many sheep it had. This information is provided in many of the surviving accounts of medieval demesne farms. Among the demesnes of the Bishopric of Winchester there was a wide range of sheep numbers, from none to thousands, and the accounts provide figures from which one can calculate whether there were sufficient sheep to support the grain exported. For one demesne, Crawley in Hampshire, there is an extensive tabulation of crop yields, how much was exported, and numbers of sheep, for each year of the accounts; two sets of ten accounts, in the periods 1232-1252 and 1325-1335, are used here.<sup>30</sup> For other Winchester demesnes the published

<sup>30</sup> Gras and Gras, *Economic history*, pp. 338-419.

TABLE 4. Cereal production that could be supported by the phosphorus transported by one sheep in a year (= 254 g)

	<i>Peas, beans</i>	<i>Wheat</i>	<i>Rye</i>	<i>Barley</i>	<i>Oats</i>
Concentration of P in grain (g/kg)	4.0	3.6	3.1	3.1	3.6
Weight: volume (kg per bushel) <sup>a</sup>	25.1	23.9	22.9	20.5	16.0
Amount of grain containing 254 g of P (= grain supported by one sheep)					
weight (kg) <sup>b</sup>	63.4	70.4	81.8	81.8	70.4
volume (bushels) <sup>c</sup>	3.0	3.5	4.2	4.7	5.2

Notes:

<sup>a</sup> Wheat 64 troy pounds per bushel (see R. D. Connor, *The weights and measures of England* (1987)); others based on 1791 statutes (see Campbell *et al.*, *Medieval capital*, p. 41). Air-dry weight, containing 15% water.

<sup>b</sup> Oven-dry weight.

<sup>c</sup> Calculation for wheat:  $254 / (3.6 \times 23.9 \times 0.85)$ . 0.85 converts from oven-dry to air-dry.

pipe rolls for 1210–11 and 1301–2 are available.<sup>31</sup> Export from the farm is taken to comprise what is recorded as sold (including sold at the audit), sent to other villages, plus the tithe, and also other amounts occasionally given to outsiders (e.g. taxes). Not included in the export are grain retained for sowing, fed to animals, payment in kind to villagers, provisions for visitors. This implies that nutrients in food eaten by villagers and visitors found its way back, via their excreta, to the demesne fields. This is unlikely to have been entirely true. Set against that, some of the tithe may have been eaten by the rector, his family and servants and so retained rather than all exported. These two imponderables will to some extent balance each other. If any seed was bought or otherwise brought in from outside, that is subtracted from the export.

For each demesne, the amount of each crop exported has been calculated, and then divided by the relevant figure from the bottom line of Table 4 to calculate the number of sheep needed to support that export. The number of sheep needed to support the total export of all the crops in that year was thus calculated. The number of sheep actually present varied through the year, as lambs were born, animals died, adults were bought and sold, received from other villages or sent to them. Any animal that arrived in the demesne during the year or left it during the year is counted as a half. Thus, the number of sheep is taken as the average of the number present at the beginning and the end of the accounting year. Lambs are further divided by 2 to allow for their smaller size and hence less manure production. This provided the basis for calculating 'sheep units', equivalent to the number of adults present for the whole year.

Table 5 shows, for a selection of Winchester farms, the number of sheep present and the number needed to maintain the soil fertility. The top three in the list are farms with large numbers of sheep, from almost 1000 to more than 2000. According to the calculations, they had ample sheep to maintain the fertility of the arable in the periods for which data are given. The remaining five farms on the list had fewer sheep; nevertheless, the number of sheep was

<sup>31</sup> N. R. Holt (ed.), *The pipe roll of the Bishopric of Winchester, 1210–1211* (1964); M. Page, *The pipe roll of the Bishopric of Winchester, 1301–2* (Hampshire Record Ser. 14, 1996).

TABLE 5. Sheep present, and sheep needed to maintain the fertility of the arable, on some demesnes of the Bishopric of Winchester

	Year <sup>a</sup>	Sheep per demesne		Sheep per sown acre	
		Present	Needed	Present	Needed
Crawley, Hants	1232-52	1462	695	3.8	1.8
	1325-35	922	287	4.4	1.4
Twyford, Hants	1211	1798	305	3.6	0.6
	1302	2217	771	4.6	1.6
Downton, Wilts	1211	2560	983	3.5	1.3
	1302	2018	691	3.6	1.2
Beauworth, Hants	1211	264	121	NI	NI
	1302	211	180	2.1	1.8
Wield, Hants	1211	391	337	NI	NI
	1302	508	245	4.4	2.1
Ivinghoe, Bucks	1302	274	588	1.1	2.3
Rimpton, Somerset	1211	247	218	1.5	1.3
	1302	?0	548	?0	2.0
Harwell, Berks	1211	41	364	NI	NI
	1302	0	220	0	NI

Note:

<sup>a</sup> Year given is the end of the account year.

NI: areas which were recorded as customary acres, so sown area not known.

Sources: Crawley, Hants: figures drawn from Gras and Gras, *Economic and social history of an English village*, pp. 338-419; other figures for 1211 from Holt (ed.), *Pipe roll, 1210-11*; for 1302 from Page (ed.), *Pipe roll, 1301-2*.

adequate at Beauworth in 1211 and Wield in 1302. Where the required number of sheep was about equal to the actual number (Beauworth 1302, Wield 1211, Rimpton 1211), in view of the various approximations in the calculations we should be cautious about deciding whether the fertility would be maintained. Other examples (Ivinghoe, Harwell) show that some of the Winchester demesnes certainly could not rely on their sheep to maintain the fertility of the arable. Rimpton accounts reported no sheep between 1271 and 1324.<sup>32</sup> However, the account for 1302 does report the cost of paying a shepherd and buying hurdles for the fold. Thornton has suggested that sheep from other Winchester demesnes were being pastured at Rimpton during this time.<sup>33</sup> So the number of sheep there in 1302 is uncertain.

Changes in soil fertility would be slow; changes in soil P status would take decades or longer to affect crop yields significantly. It is therefore unfortunate that, apart from Crawley, the data in Table 5 are for only two individual years. It is possible that in some years the amount of crop exported or the number of sheep was atypical for that manor. The number of sheep can be checked against mean numbers for longer periods: Titow gave the mean number of sheep

<sup>32</sup> Titow, *Winchester yields*, Table L.

<sup>33</sup> Thornton, 'Determinants', p. 198.

TABLE 6. Sheep present, and sheep needed to maintain the fertility of the arable: figures for some non-Winchester demesnes

	Total sheep		Sheep per sown acre	
	Present	Needed	Present	Needed
Cuxham <sup>a</sup>	100-150	388		2.2
Peterborough <sup>b</sup>	6521	7931	1.3	1.6
S. England <sup>c</sup>			0.95	1.1-1.3

Sources:

<sup>a</sup> Cuxham, Oxfordshire, 1320-1340. Data from Newman and Harvey, 'Soil fertility', Table 4; Harvey, *Medieval village*.

<sup>b</sup> 23 demesnes of the Abbey of Peterborough, data from three accounts 1301-1310. Data from K. Biddick, *The other economy* (1989), Tables 12, 20, 29.

<sup>c</sup> About 200 demesnes in central and south-eastern England, 1288-1315 (Feeding the City Database 1). Data from Campbell *et al.*, *Medieval capital*, Tables 1, 2, 15; Campbell, *English Seigniorial agriculture*, Table 4.03.

on each Winchester farm for 1209-1270 and for 1300-1324, which can be compared with the individual years 1211 and 1302, respectively.<sup>34</sup> Most of the sheep numbers given in Table 5 are broadly in agreement with the period means, close enough not to alter the conclusion about whether soil fertility would be maintained. Exceptions are: Wield, where sheep averaged 246 in 1209-1270 and 304 in 1300-1324; and Rimpton, 131 in 1209-1270. Although Harwell's 1302 account reported no sheep, it averaged 45 during 1300-24, but still far too low to maintain soil fertility.

Table 6 presents data for a wider range of manors. Cuxham, Oxfordshire, a manor of Merton College, Oxford, is an example of a non-ecclesiastical demesne for which medieval accounts survive.<sup>35</sup> It was primarily a grain-producing farm: it had only a small area of pasture and meadow. During most of the period from 1311 to 1357 there were 100-150 sheep, but in some years fewer. Table 6 shows that this would have been inadequate to maintain soil fertility. Newman and Harvey calculated nutrient balances for the whole demesne, assuming that nutrient transfer within it was efficient, and also concluded that the phosphorus balance was not being maintained.<sup>36</sup>

The Abbey of Peterborough held 23 demesnes in the early fourteenth century, and accounts survive for the years 1301, 1308 and 1310. Biddick provided tabulated figures from them, which allow calculation of the total number of sheep needed to maintain fertility. Averaged over the three years, the number of sheep present was somewhat lower than the number needed (Table 6).

A large database ('Feeding The City 1') has been built up by Campbell *et al.*, containing data extracted from accounts of about 200 demesnes in central and south-east England during the period 1288-1315. Some of the Peterborough demesnes and a few of the Winchester demesnes are included in this database, but most of the Winchester demesnes were outside its area. Published tables provide almost all the data needed to calculate the number of sheep needed per sown acre to maintain soil fertility during this period. The only relevant data missing are exports of legumes; the amount of legumes exported is here assumed to lie between none and

<sup>34</sup> Titow, *Winchester yields*, Table L.

<sup>35</sup> Harvey, *Medieval village*.

<sup>36</sup> Newman and Harvey, 'Soil fertility'.

60 per cent of the yield. The calculations show that on average the demesnes in this area did not have enough sheep to maintain fertility. However, among these demesnes, and those in the Peterborough estate, the amount of export and the number of sheep presumably varied, so some may have had enough sheep; but some did not.

The two right-hand columns of Tables 5 and 6 give the numbers of sheep present and needed divided by the number of acres sown to crops. I have made the same calculations for some of the other Winchester demesnes, for 1211 and 1302.<sup>37</sup> The number of sheep needed per sown acre varied quite widely, from below 1 up to 2.3. These figures vary too widely to provide a precise rule of thumb; but it is worth noting that for the majority of these demesnes the number of sheep needed per sown acre was in the range 1–2.

## VI

This paper has considered only one aspect of the nutrient balance of medieval farming, the contribution of sheep folding. There would be other nutrient inputs to arable land, including nitrogen dissolved in rain, as dust, as gases, and phosphorus and potassium by weathering of soil particles. There would also be losses of nutrients in addition to the amount in crops, including that dissolved in percolating water, by soil erosion, as gases. This paper has been further limited to considering only the sheep belonging to the demesne. In many vills the peasants also owned sheep, and often these were folded on the demesne arable for part of the time. Numbers of non-demesne sheep are rarely known, but where there is evidence it indicates that the peasant flock could be substantial. So the contribution of non-demesne sheep to fertilizing the demesne arable could have been important.<sup>38</sup>

This paper has concentrated on sheep, ignoring the fertilizing effect of manure from other animals. There is no intention to imply that manure from cattle, horses, pigeons and other animals was unimportant. The reason for considering only sheep here is that stalled animals require a different sort of calculation, taking into account how much time each year they spent indoors, and what they were fed on. Their contribution to maintaining the fertility of the arable deserves careful consideration, but needs to be the subject of a separate paper.

If nutrients are transferred from pasture to arable, this is a gain for the arable, but a loss from the pasture. So was the fertility of the soils in grazing land declining over time? In other words, was the area of grazing land inadequate to support the arable production? If so, the system was not sustainable long-term: the productivity of the grazing lands would gradually decline, fewer sheep could be supported and less nutrients be provided to the arable. The key question is whether natural inputs of nutrients to the grazing lands were sufficient to balance removals by sheep, and other losses, e.g. leaching by downward water flow. This paper has estimated transport, in kg per sheep per year, at: N 2.9, P 0.25, K 2.3. Was the area of grazing

<sup>37</sup> The sown area reported in the accounts was for the following year, not the year in which the yields and exports were reported. However, since the calculations involve the total sown area on the demesne, not the area for each crop, it is likely that usually there was no large change from one year to the next.

<sup>38</sup> M. Bailey, *A marginal economy?* (1989), pp. 65–85; Dyer, *Standards of living*, pp. 128, 143; Dyer, in *Agrarian History*, II, p. 377; R. H. Britnell, in *Agrarian History*, III, pp. 200–203; Miller, in *Agrarian History*, III, p. 290; Postan, *Essays*, pp. 214–248; Gras and Gras, *Economic history*, p. 45.

available per sheep large enough to be receiving such amounts in natural input? Some figures for rates of natural input were provided by Newman and Harvey.<sup>39</sup> The range of possible values varies widely, but example values (in kg per hectare per year), taken for the purposes of illustration, are: N 5 (mainly N fixation from the air by clovers and other legumes), P and K 0.2 and 2 respectively (mainly from weathering of soil particles). At these input rates, the areas of pasture needed to supply the nutrients taken by one sheep would be 1.4, 3 and 3 acres, for N, P and K respectively. Therefore 3 acres of pasture might provide enough nutrients to support production and export of 3–5 bushels of grain. Was it common in medieval times for 3 acres or more of grazing to be available per sheep? Unfortunately, the total area of grazing land, including common grazing, was not usually recorded, so any general statement about area available per sheep is not possible at present. This topic – whether or not the fertility and productivity of grazing land was degraded by sheep-corn farming – is an important one, which cannot be adequately covered here, but which merits further research.

This paper, and the method of calculation it presents, is therefore only one part of a complete nutrient balance calculation for medieval agriculture. Nevertheless, it does allow tentative conclusions. It is likely that non-sheep nutrient inputs to the arable (i.e. natural inputs plus manure from cattle and horses) were usually sufficient to balance losses other than in crop export.<sup>40</sup> Therefore, where the number of sheep present was more than the number calculated to be needed to balance nutrient losses in crop export, this provides grounds for concluding that the fertility of the arable was being maintained. This paper has thus provided a means of identifying demesnes where the nutrient status of the arable was being maintained, and has shown that this was true for some of the Winchester demesnes. Titow wrote of the Winchester demesnes: 'The supply of manure ... was so low throughout [1209–1349] as to justify talking in terms of a chronic state of undermanuring'.<sup>41</sup> The results presented here do not support that generalization.

The database of manorial accounts for 1250–1449 assembled by Professor Campbell, which covers demesnes throughout England, provides information on how numbers of sheep and sown acreage changed during that period.<sup>42</sup> Between 1250–1299 and 1400–1449, sown acres declined while sheep numbers increased. The average number of sheep per sown acre in 1250–99 was 0.6; in 1300–49, 1.1; in 1350–99, 1.6; and in 1400–49, 1.9. Since the required number of sheep to maintain fertility often lies between 1 and 2 (Tables 5 and 6), it is likely that the numbers were inadequate on most farms before 1300, but during the next 150 years progressively more farms had sufficient sheep to maintain fertility.

Postan, in his oft-quoted book, stated that 'the continuous reduction of pasture could threaten the viability of arable cultivation itself ... By the end of [the thirteenth century] and the beginning of the following century, in corn-growing parts of the country taken as a whole, pasture and the animal population had been reduced to a level incompatible with the conduct of mixed farming itself'.<sup>43</sup> This paper has shown that it would be unwise to accept that generalization. In the early fourteenth century some demesnes evidently had enough sheep to

<sup>39</sup> Newman and Harvey, 'Soil fertility'.

<sup>40</sup> Ibid.

<sup>41</sup> Titow, *Winchester yields*, p. 30.

<sup>42</sup> Campbell, *English Seigniorial agriculture*, Tables 4.03, 4.07.

<sup>43</sup> Postan, *Medieval economy*, p. 65.



ensure the maintenance of the fertility of the arable land, though other demesnes probably did not. It would be desirable to carry out more detailed calculations of nutrient balances of farms in different regions of the country, and comparing different agricultural regimes. This paper has provided information and methods to help with such investigations.