Flows of matter in a traditional heathland farm about 1840. An example from northern West Jutland, Denmark

Sofus Christiansen

Abstract

A specific type of traditional, coupled infield-outfield farming, related to 'plaggenwirtschaft', is analysed on the basis of a diary 1829-57 with the aim of understanding functions and effects of the farming system in relation to landscape physiognomy. Applying normative values to the figures of the diary, the flows of matter are quantitatively estimated. Transfer of plant nutrients from meadow to infield via livestock not only supplied much needed fertilisers (N, P and K) but had lasting and improving impacts on soil retention capacities for ions and water, thus facilitating cultivation. The role of the heathland in supplying organic matter to absorb dung from cowshed and farmyard and as a soil improvement material was important. The constant depletion of nutrients from the heathland was decisive for its conservation. An analysis similar to the one presented was to be paralleled by field experiments (at a site at Hjerl Hede) in order to quantitatively confirm central findings.

Keywords

Heathland, farming system, infield-outfield farming, plaggenwirtschaft, agricultural ecology, flow of matter, soil improvement, conservation of heathland.

Sofus Christiansen, Institute of Geography, University of Copenhagen, Øster Voldgade 10, DK 1350 Copenhagen K, Denmark

Geografisk Tidsskrift, Danish Journal of Geography 101: 43-66

Understanding landscapes, their origin and dynamics - which is an important part of geography - requires insight into the shaping processes. It is widely known, that many landscapes formerly perceived as 'wild nature' (e.g. heathlands) in reality owe their physiognomy to a history of utilisation. Further analysis of the ancient heathland farming systems has thus attracted interest not only from historians and cultural geographers, but also from much larger circles (such as nature conservationists, natural historians etc.). These groups seek to understand the genesis and maintenance of cultural landscapes. The following will contribute to the insight into Danish heathland farming and its landscapes in the first half of the 19th century and serve as a planning tool for field experiments by identifying points of specific importance.

A widespread form of land utilisation before industrialisation was the infield-outfield farming system: a main form of 'concentrational farming' which dominated world agriculture at that time. Specifically in its so called coupled form' infield-outfield farming had interesting qualities as a farming strategy for meagre lands (Christiansen, 1978; Rasmussen, 1979). In Denmark one form, 'the river-valley system', has been aptly described by Jensen & Jensen (1979) and by Gormsen (1991). Similar types are known from most of the quaternary sandy areas of northwestern Europe and had in the Netherlands and Germany attained a high degree of perfection. Including such types as 'plaggenwirtschaft' - by which sods (plaggen) were used as absorbing media for dung and later as manure in the field, the 'es', - and the use of cowsheds, 'potstalls', that were specially designed to accumulate and store manure, these system were developed to a stage of high refinement, pro-ductivity and sustainability, based solely on local resour-ces. (Re. 'plaggenwirtschaft': see Delfs, 2000).

In spite of the growing interest in these forms of agriculture few detailed accounts of their function exist. The main features have been described in much literature (e.g. Uhlig, 1961; van Bath, 1963; Lambert, 1971). The farmer's strategy was clearly to transfer 'fertility' (plant nutrient elements) from the meadows to the in-fields by means of his ruminant livestock, whereby he could increase yields significantly. Attention has also been drawn to the heath-lands' contribution to the system in several ways (Jensen & Jensen, 1979; Stoklund, 1990).

The aim of the approach described in the following was to prepare a first analysis of the flow of matter, specifically plant nutrients, in characteristic Danish heathland farming at its peak of development prior to industrialisation. The attempt was based on very detailed information from a unique diary written by one Peder Knudsen, a heathland farmer who lived 1798-1857 in Staulund near Haderup River, a tributary to Karup River, in the western part of the large Karup heathland plain He meticulously kept his diary from 1829 to his death 28 years later. Gormsen (1982, 1991) has thoroughly analysed the diary in many aspects, specifically regarding the farming activities - definitely its main theme - and the facts from her analyses have here been used in an attempt at compiling an overview of the main flows of matter of the farming system.

In spite of its many virtues, Peder Knudsen's diary was for personal use, i.e. mainly as a tool for improving and facilitating his farming. This means, that it contains only what he considers worth noting, and little else. Specifically dates and yields, as well as other useful data for optimising use of his scarce fodder resources etc., were given attention, whereas other - for our purpose important - information was totally ignored. The useful facts reported in the diary have thus necessarily been supplemented with other information and considerations to arrive at a reasonably coherent picture of his farming.

Since the main mechanism of the transfer from meadow to infield, using heath-materials as auxiliaries, is of specific interest, further analysis by a functionally reconstructed field experiment was attempted at the same time. Unfortunately, this had to be abandoned prematurely, mainly because the areas available for the experiment proved unsuitable. The need for further experiments persists, and has only become more clearly identified and urgent in the meantime.

Peder Knudsen's farm

Site and environment

Peder Knudsen's farm encompassed an area of around 300 hectare land (560 *tønder land; tønde* - abbreviated td., plural tdr. - is roughly 5,500 m² or about 1/3 larger than one acre), of which nearly 270 ha (400 tdr. or about 88%) were heathland. Only 30.3 ha (55 tdr.) were under plough, and of these about 12 ha (22 tdr) annually sown. Most important: 6.6 ha (12 tdr.) of meadow belonged to the farm. There was locally nothing unusual about the farm: area and composition were typical for the region, as were the general layout and location; only a small area was under blown sand.

Farm buildings were located on the right shores of Haderup River, high on the banks above the bottom of the valley, surrounded by the vast, almost even, heathland (part of the Karup periglacial outwash plain). Access to the meadow in the valley bottom was possible through one of the small, mostly dry, side-valleys to the larger one of Haderup River valley. Some of the more prominent side-valleys, like Stangsdal (Stumpedal) to the north and Gråmosedal to the south, were wet in places, had boggy soils and a more lush vegetation. Also the heathland, lying at an elevation of about 30-35 m above sea level, though generally well drained, had a few small basins with bogs. Otherwise the large plain was in heather and totally treeless.

Because of the poor soil quality, possibilities for farming the heath plain were quite limited. Table 1 (shown at the end of the text, where tables have been located for convenien ce) reveals soils of relatively uniform texture: coarse sand at all sites, except where blown sand has accumulated (Gindeskov 15). Clayey fractions are almost totally absent throughout. Ion binding capacity thus depends largely on the organic contents of the topsoil.

Generally the soils display the three classical horizons: a turfy top of organic mor (0-10 cm) covers bleached sand down to 45-90 cm, below which red, oxidised sands dominate, often with a dark top horizon about 10 cm thick, impregnated with humous or ferrous materials (in Danish: al). The mor-layer under the heath vegetation normally had an organic content slightly over 4%. Nowadays the area has been ploughed, and the uppermost 25 cm mixed to a relatively uniform horizon as appears from Table 2.

The 'modern' soil has been treated by marling and fertilisation, but is still poor. Within a tilling depth of 25 cm the stores of nitrogen (N), phosphorus (P) and potassium (K) are quite modest: about 2.25 tons/ha, 7.3 kg/ha and 140 kg/ha respectively, bound to about 70 tons/ha of humus - but with even more unavailable to plants. Furthermore, the capacity for storing plant nutrient ions (CEC) and water remains low. The plant-available water within a root zone of 50 cm is only about 6 cm, at full capacity.

As already concluded by Weis (1932), the soil can 'only after man-induced changes of structure and physicalchemical components ...be turned into a substrate for active biological development'. In other words: cultivation is next to impossible, unless plant nutrients are made available/accessible and water availability improved. The transfer of plant nutrients and improvement of the retention capacities for nutrients and water should be the immediate goals, achievable by 1) increasing organic contents, 2) increasing pH to neutralise acidity, by marling at the same time adding a clayey fraction of particles, and - effective also in the short run - adducting plant nutrient ions. The low quality of the soil highlights the fact that climate very often could turn

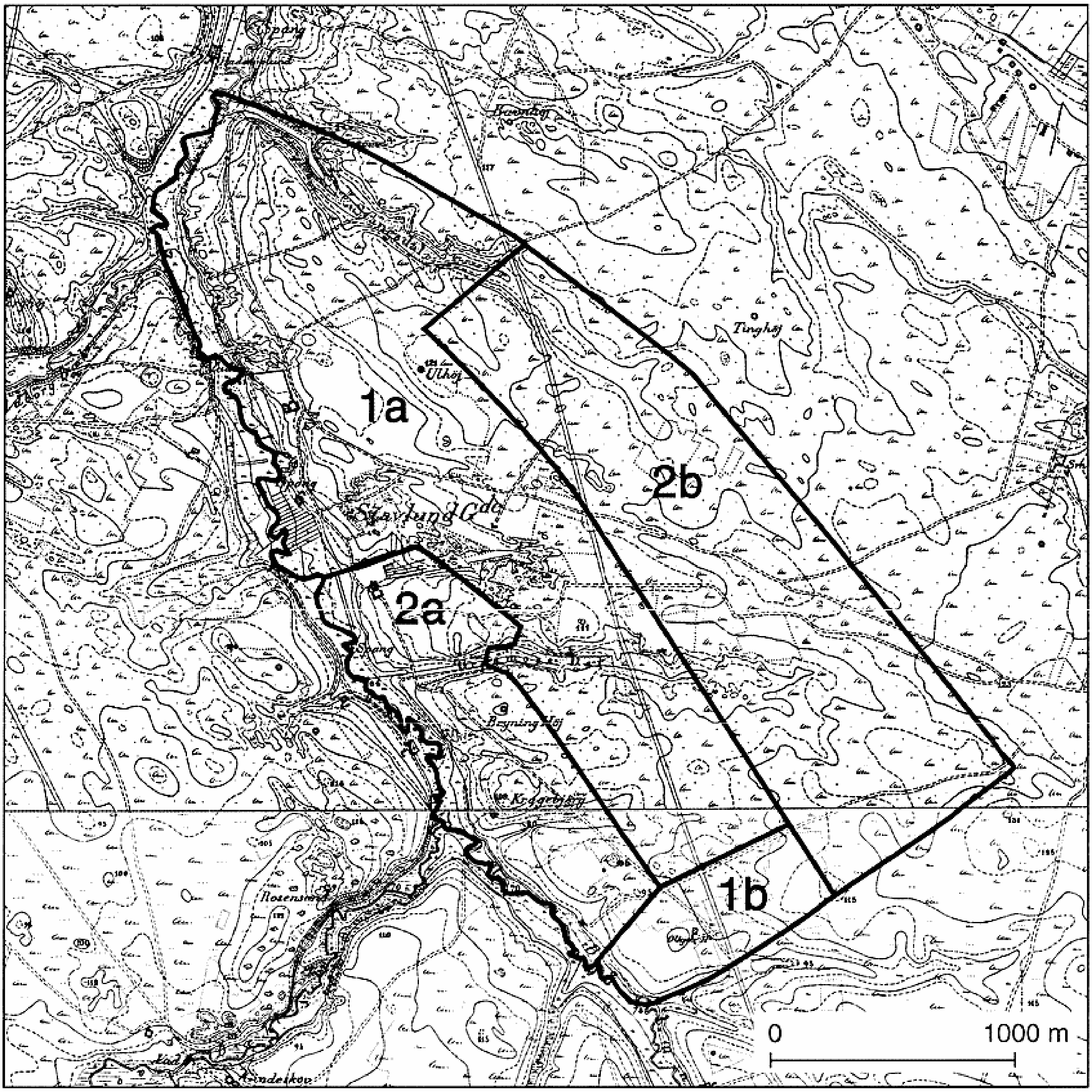

Figure 1: *Peder Knudsen's farm, shown on cadastral map T 17 Haderup 1873 with boundaries as of 1817. Parcel 1 a was Peder Knudsen's and 1 b belonged to his brother Niels as part of his inheritance. Parcel 2 a and b were owned by Peder Jacobsen, a relative (?). All parcels shown were originally parts of one 'double-farm'. Contour interval: 5 ft. Areas with heather and moorland have signatures, cultivated land is without signature. By permission from Kort-og Matrikelstyrelsen.*

water- availability into a pressing issue in late spring-early summer (See Table 3).

With a soil magazine holding only about 60 mm equivalent of precipitation most of it was, of course, soon lost to evapotranspiration. Early in the growth-season starting late April-early May, water-losses in vapour-form increased to a level whereby the stores could be emptied before the end of May, barring rain. Drought was thus a persistent danger for cereal crops: a stretch of three rainless weeks could ruin them totally.

Principles of heathland use

For the users of the heathland throughout history the aspects mentioned must have appeared grim. Low plant-productivity required all farming utilisation to apply some principle of concentration, either by extractive use by grazing/browsing animals or by a type of concentrational farming or a combination of the two categories. Utilisation by grazing cattle or sheep (possible even in winter) or by swidden agriculture were practised as long as sufficiently large areas were available. No doubt, however, the principle of using cow-dung from the winter's stable-feeding to fertilise small areas, otherwise uncultivable, was known. Already in the palaeolithic, cultivation around the pole-built villages in Switzerland was based on this principle (Troels-Smith, 1984) like also Danish iron-age cultivation. More sophisticated uses of dung for mixed manure were known in the Netherlands from about 1140 (Lambert, 1971).

Local conditions were permissive, if not directly favourable, of practical applicability of this principle. Meadows provided a high and stable vegetable productivity of good fodder, and the heathland, though more sparsely vegetated, could supply some feed even in winter. Most important, vegetable materials were available for various other uses, including desirable soil improvement in the heathland.

At the beginning of the 19th century the infield-outfield principle commonly functio ned to link the two main elements into a system for fulfilment of the 'meadow fattens field' principle (for a general description in Danish: see e.g. Blicher, 1839). Usually the system had an auxiliary subsupplier - the heathland - and the transfer of matter was largely by means of grazing ruminants supplemented with carting of manure as indicated below.

The main supply of plant nutrients and organic materials thus stemmed from local, self-regenerating 'outfields', meadow and heathland. Much of the material passed as fodder through the livestock stabled for the winter. The animals were the main converters of fodder into food, dung and other soil improvement materials. From the cowshed - via the midden, where the materials were mixed and nutrients released by decomposition and also deconcen trated to form a type of compost - they were carted off to their final use on the (in)-field. Via the crops a part of the materials was recycled back to the stable as feed for the livestock (barley, oats and straw).

The practices can as a whole be seen as a single, composite mechanism for utilisation of the heathland, but also as the merging of two mutually beneficial systems. One is livestock producing, based on the meadow (producing milk for daily consumption, bullocks for sale etc.). The other is an 'additive' system producing cereals for sustenance and sale, enabled by the meadow-system. Though it is tempting to regard the livestock part of the system as the basic one, the palynological record does not support this view unbiased (see Odgaard, 1994). The huge areas originally attached to the heathland farms may equally well point at the heathlands as the main base for an early farming, probably through shifting cultivation with swidden, combined with husbandry of grazing/browsing animals. Though of ancient origin and previously well known, the 'river-valley' system can possibly be seen as a late adaptation to increased demands for farmland or an effect of the emergence of attractive markets for livestock.

Flows of Nutrients in Peder Knudsen's Farming System

In the following each of the 5 main 'elements' of the farming system of Peder Knudsen will be described and their function commented upon. The specific flow of matter from each element will be assessed and referred to in relation to the system by means of a letter, as shown in the diagrammes Figure 2. Corresponding to the flows of the diagramme, tables with quantitative data can be found at the back of the paper

1. The meadow

Location and vegetation

Peder Knudsen's 13 tdr. of meadow-land was not one coherent piece, but divided into several small parts by the meanders of Haderup River. These were distributed over a stretch of more than two kilometres. Though protected from the river by low levées, the meadow was usually flooded in early spring, depending on level and drainage. Where conditions were best, 'sweet' grasses dominated, but in many places a vegetation mixed with reeds and sedges made the meadow less useful, both for grazing and for hay-making.

The more distant parts of the meadow were apparently solely used for hay-making; grazing was most intensive where access to the farm and farmyard was easy. Meadows high enough to avoid regular flooding, were tilled and sown with oats or buckwheat. Overall, the meadow was fully utilised, according to the rule of 'best use' in the contemporary sense.

Function of the meadow

The central role of the meadow was - as mentioned before - to supply the livestock: in summer through grazing, in winter from stored hay. According to a traditional rule of thumb one td. land of meadow was necessary/sufficient to supply one head of cattle. Hence Peder Knudsen's 6,6 ha (= 13 tdr. land) were used nearly to capacity to sustain his 2 horses, 3 bullocks, 3 cows and 5 heads of young cattle. According to Hannerberg (1972) these corre spond namely to 2 x 1½ + 3 x 1 ¼ + 3 x 1 + 5 x ½ = 12 ¼ 'animal units' (bullocks: estimate by author).

Since Peder Knudsen's meadow until 1834 was without irrigation and only with limited (open-ditch) draining, its production of palatable grasses must have been modest. Sedges, rushes and reeds occupied part of the area, and the higher areas of the meadow were used for a modest cultiva-

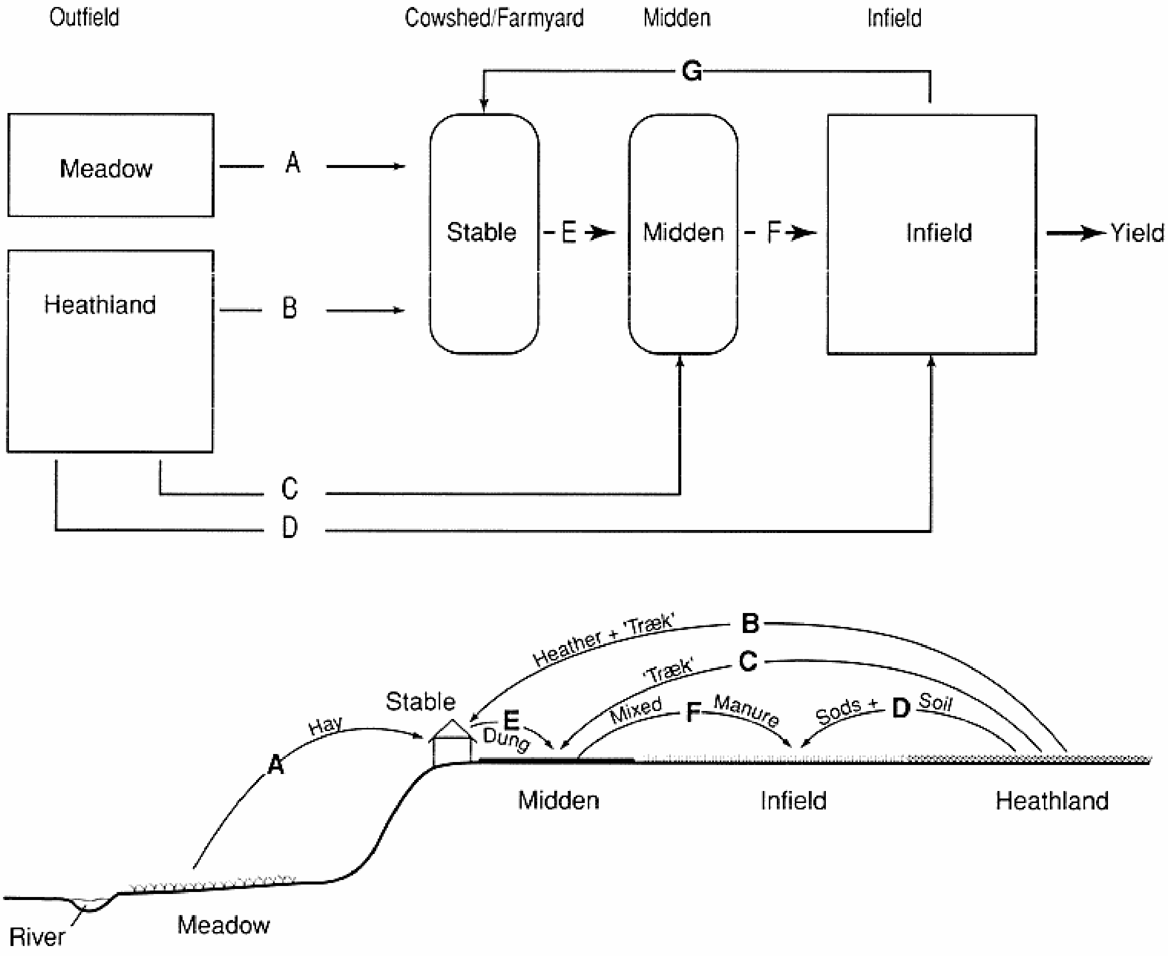

Figure 2. Above: Main flows of materials. Types of materials indicated Below: Main flows shown on idealised cross-section. Flow G has been omitted for clarity. Note: træk is a thinly-cut type of heather-turf (about 5-7 cm thick), consisting mostly of organic matter of litter and roots. Sods were cut thicker (about 10 cm), and was mainly turvy material. Klyner were moss-turves, mainly when developed from Sphagnum - moss, found i.a. in Grámosedal.

tion of oats and buckwheat. No doubt, Peder Knudsen expressly wanted to use his meadow more fully, as he saw it as determining most of his supply of coarse fodder and hence the number of livestock, as well as - via the animals' production of manure - limiting the yields of the infield.

A small but puzzling detail is that Peder Knudsen apparently without any significant problems handed over a part of the meadow to his brother Niels. If this means that distant parts of the meadow were less utilised, a smaller area than the 6.6 ha mentioned should be used as basis for the estimates in the following. To account for this a somewhat reduced productivity has been ascribed the meadow to correspond with known information on yields.

Productivity of the meadow

The meadow's productivity was clearly a decisive parameter, yet it is difficult to assess. This is due to the fact that Peder Knudsen's management of meadow areas for grazing versus hay-making (e.g. by fencing off parcels or by tethering animals) is not directly described in his diary. Only one meadow activity, hay-making in Engkrogene, is described in more detail. Unfortunately much information, though essential information in the present study, is missing from the diary since it was a trivial fact for Peder Knudsen. Hence, data on the productivity of the meadow must be found in other ways. In the following three different approximations shall be attempted.

The diary does at least allow us to estimate the amount of winter fodder. The day of the beginning of the hay-harvest is noted, indicating that without irrigation only one annual harvest was taken (late July). Additionally it is recorded, that the harvest amounted to 29 cartloads (each assumed to be about 350 kg), corresponding to some 10.2 tons ('tons' are metric tons, abbreviated 't') of dry hay. Since the hay was meant for immediate storing, it must have been traditional 'mature hay' and further 'weather dry', i.e. with water contents about 20 %. If so, dry matter contents must have been about 8.1 tons, corresponding to contents of about 5,500 FE (Fodder Equivalents according to Danish conventions: one FE is defined as 'fodder value of one kg of barley'. One FE ~ 1.6 kg of dry matter of grass or 1.84 kg of 'weather dry' hay, L.I. 1989).

The hay harvest (supplemented with some grains and straw, occasionally also some heather) was, what Peder Knudsen's livestock had for consumption during winter (mid-October - early May, 195 days). Assuming this, and that the amount of grass/hay consumed during the active summer period was larger, a first approximation to the meadow's productivi ty must exceed 11,000 FE/yr.

Contemporary, relevant literature gives information on the total productivity of meadows, but usually without revealing what is meant by 'grass' or 'hay', an important distinction because of differences in water contents. In most cases no indication is found on this decisive question - which excludes the use of much information. Exceptions are found in modern sources: for a similar, though probably more sour, type of meadow, Nielsen et al.(2000) reported a dry matter productivity of 4.9-6.9 tons/ha, depending on grazing intensity (high intensity ~ high productivity). This corresponds for Knudsen's 6.6 ha to roughly 32 - 45 tons of dry matter or about 20,000-28,500 FE. The lower figure seems more probable for a meadow with little drainage, wild vegetation and no fertilisation. (Figure 1 shows the meadow with canals, but these were for a later irrigation). Possibly a smaller area was used by Peder Knudsen, as mentioned above. (The area handed over to Niels was probably ½-1 ha, necessary to sustain at least one cow, which was regarded the minimum for sustenance).

The information in the diary can, however, also be used to estimate total fodder consumption. A generally accepted means of calculation allows the consumption expressed in FE to be found from length of feeding period, animal species and body weights (Havskov Sørensen, 1968). To the basic estimates should then be added allowances for work, increase of body weight, milking yields etc. The assumed body-weights and figures for consumption are shown in Table 4 (page 61).

It should be noted that historically animals were much smaller than their present relatives, as were their consumption. (Size difference was clearly demonstrated when trying to fit modern animals into the boxes of an ancient cowshed. Neither bullock nor cows could be squeezed into cattle boxes).

For the very active summer-period, the 170 days from early May to mid October, the animals are (see Table 4) supposed to consume 170 x (40.8 + 16) FE = 9,656 FE. For the stall-feeding period, 195 days from mid October to early May, 195 x (40.8 + 7.5) FE = 9,418 FE, making an annual total of ~ 20,000 FE. These are low estimates, and may only be realistic, if the body weights of Peder Knudsen's animals were as low as suggested. Realising that the estimate 20,000 FE is low, and that about 6-7,000 FE were added in the form of fodder originating from the field (barley, oats and straw, excluding rye), the utilized productivity of the meadow seems to have been about 14,000 FE/year.

Table 5 (in the back) collates the three estimates of productivity for the meadow. As the meadow at that time was used to capacity and the livestock 'calibrated to size' of its productivity, serious effects of the inevitable swings of yields are not difficult to imagine. The diary gives many examples of the problems seen through Peder Knudsen's eyes. He often worried over insufficient stable fodder, fed sparingly, used heather as emergency fodder, tried to get extra straw from his neighbours, bewailed he had sold too much of his harvest etc. Once he regretted having kept a bullock, that was consuming too much. Gormsen (1991) refers to many similar examples, leaving us the impression of a farmer who, pressed hard, reflects in a very rational way over his management. Against this backdrop it is surprising that the surrender in 1831 to his brother Niels of a part of the meadow does not seem to have created problems. Whether this was due to previous underuse of this (relatively remote) part of the meadow, or to Peder Knudsen's introduction of an irrigational system in1834 remains unclear.

The 'export' from the meadow to the cowshed is given in table-format as 'Flow A'. (This is found in the back, shown together with similar tables, that together should illustrate the flows in Peder Knudsen's farm). The high contents of plant nutrients, available for plants, are noted. In spite of the continuous export of nutrients no depletion is documented, thanks to additional supplies from river- and ground water.

II. The heathland

Location and character

Most of Peder Knudsen's 270 ha of heathland were located on the top of the wind-blown plateau, carved out of the Karup plain by a series of valleys, as previously mentioned. The soil, impoverished from its historical uses was covered with a vegetation dominated by heather, *Calluna* and other dwarfbushes. In lower, more humid areas, *grønninger* (Danish: green areas) a different vegetation with grasses and herbs to complete shrubs of which *Arctostaphylos, Empetrum* and *Salix* were the most conspicuous. In more exposed, windblown places lichens, like *Cladonia*, and a few mosses (*Hypnum* e.g) were seen. Like the meadow, the heath was used for supplying matter, in this case both to cowshed, midden and possibly infield. The vegetation was, hence, constantly held in a suppressed stage.

Utilisation

Peder Knudsen apparently extracted everything, for which he could find a use, from his heathland. Main categories of uses were for:

- fodder and bedding for animals,
- materials for soil improvement and
- fuel.

In general, heather was a material of thousand uses for the heathland farmer (see e.g. Højrup, 1970). The uses, discussed in the following, related much to the age of the vegetation and have been summarised in Table 6.

Fodder

Peder Knudsen's 50 sheep lived directly from the heathland by *grazing and browsing* and were fed only in exceptional cases (e.g. in severe winters). If sheep are assumed to consume about 0.3 FE per day (which is a low estimate), their annual consumption was 5,475 FE, corresponding to about 36 tons of dry, digestible matter (about 60 tons of live heather at 40% water). Young heather shoots (1-2 years old) would normally be eaten. Because of heather's regenerative abilities, sheep could browse almost everywhere in the heath.

Further, the heathland supplied *fodder* to the cowshed/farmyard: about 6 cartloads, 2.1 tons of *fårelyng* (winter-fodder for sheep) annually, which may amount to about 1.5 tons of dry matter. Usually heather at the developing stage, relatively young, would be used.

Supplying *træk* (for use as litter in the cowshed and in the farmyard) was one of the most destructive forms of heathland-utilisation, but very important for the whole system. About 70 cartloads of *træk* were delivered annually, which were peeled off to a depth of 5 -10 cm from the heath, leaving bare mineral soil in its wake. The 70 cartloads represent about 24.5 tons, which - assuming a specific weight about 0.25 (compression and a certain admixture of mineral soil assumed) - equalled a volume of about 100 m^3. This volume would imply the peeling of about 1000 m^2 of heath, if the thickness of the *træk* -layer were 10 cm. This almost equals the farmyard and the floor of the cowshed: the area that was kept covered by *træk* functioning as litter. Use of træk implied a slow regeneration of the vegetative cover. It was generally assumed to take about 70, sometimes up to 100 years, which sounds possible, since a reinvasion of the areas were necessary.

Bedding

Further, 3-4 cartloads of heather for bedding in the cowshed were also supplied annually, representing about 1,050 kg (or 630 kg of dry matter/yr) - but of older plants.

Materials for soil improvement

For the preparation of mixed manure in the midden some jord, literally 'soil' (but rather to be understood as 'soil, rich in organic matter', such as heath-turves, mud or previously cultivated soil) was taken from the heathland in astonishing, but varying, quantities.

In one specific year 230 cartloads or about 80 tons were reported brought into the farmyard midden, taken from unidentified areas (probably from valley-bottoms or small basins, where sods or turves were thick, or from an already improved field-area). The organic content is difficult to estimate, probably it amounted to some 4 tons (assuming 5% of organic contents). If enriched soil were used, this figure would apply. Were the 230 cartloads instead *træk*, the organic contents would be about ten times higher, about 40 tons.

In many years the farmyard midden was duplicated and a reported total of over 500 loads carted to the field. At other occasions middens of similar size were made directly in the field to be cultivated. What matters seems thus to be the amount of mixed dung collected, not its location. In the following it is assumed, that the farmyard-midden of 300 cartloads mentioned above was supplemented by extra middens (in yard or field) of some 300 cartloads, totalling a store of mixed dung totalling about 600 cartloads (or 210 tons). In any case, middens totalling 600-700 cartloads seem to have been commonplace, and even larger amounts are reported from time to time. Hence the flows C and D (see these) are functionally similar. The difference as to their place of origin is of little consequence, except when related to transport, but their compositions are of course decisive. No doubt the idea was to get all available dung mixed with soil-fill (as rich in organic contents as possible) in order to preserve plant nutrients by keeping them at relatively low concentrations - and.possibly this also to facilitate dosage and spreading of mixed dung.

Though concentrations in mixed dung were low, total contents of NPK were not unimportant in spite of the fact that most of the materials stemming from the heathland were, at least for some time, uanavailable for plants (not considered in Flow C and D). The origin of materials remaining unreported, it seems clear that high organic content was aimed at, but difficult to achieve. Common sources were træk, turves, mud and even enriched soil from fallow field areas. If træk was used instead of soil for fill, the content of nutrients was tremendously increased.

Ash-'fertiliser'

In preparation of *hedeager* (roughly corresponding to 'outfield' in English/Scottish sources), sometimes a piece of 'mature' heathland was burnt off and then tilled. The heather should preferably be no less than 10 years of age, and it was usually burnt together with additional sods from adjacent lands. Probably around two ha of heathland were burned annually with a recovery-time of about 30 years. For continuous utilisation hedeager thus required about 40-50 ha, quite a large piece of land for a modest yield of about 2 tons! Usually the burnt area was sown with rye and gave a reasonably good yield, as well as being almost totally free from seeds of weeds. Swidden rye hence demanded a high price as a seeding material. Largely, the use of the hedeager did not imply any transport, i.e. no flow. Yet, in many cases, some additional fertiliser (dung, sheep's dung or ashes) was added. This is not reported here. Ash-fertiliser also was produced using heathland fuel materials, as will be examined below.

Fuel

Heather for fuel was in high demand, if it was old and woody. It was easy to ignite, reached high temperatures quickly, and burned almost smokeless. It was therefore used for heating ovens for baking and for igniting the turves when heating houses etc. Three cartloads were cut annually, corresponding to some 1,050 kg, or 840 kg of dry matter.

Heather, sods and turves were generally used for heating of houses. About 70 cartloads (24.5 tons) were annually cut and brought to the farm, where they were orderly stacked along the walls of the dwelling house for drying and at the same time provide improved insulation for the winter. The sods were slowly developed, mainly in the richer and wetter parts of the heathland. Sods were peeled off to a depth of at least 10 cm and probably required about 70 years for regeneration. Ashes from oven and fireplaces were collected in a special little heap, mixed with other refuse and added to sheep's dung to be used for fertilising. Specifically this type of manure was used in the high parts of the meadow e.g for buckwheat and for potatoes in the field or heathland. The ashes contained almost none of the original N -content, but 70% of P, and 80 % of K.

Klyner, turves from Sphagnum-mosses, were apparently of use neither for heating nor for soil-improvement. They were now and then used to make charcoal for sale, but their low content of plant nutrients and fast decomposition made them less attractive than træk as soil improvers.

Apart from the activities dealt with above there were several others, occurring at less regular intervals: construction of dikes, thatching of roofs, repairing of roads, covering of blow-outs etc. The heathland to be set aside for such miscellaneous purposes can hardly be estimated, but is not insignificant. It should be noted, that multiple uses were common. Were the sods not used for heating and had become old and loose, they easily found an alternative use in soil improvement etc. In reading Table 6 this should be borne in mind - together with the other sources of inaccuracies so far mentioned.

Productivity
In relation to utilisation of heathland, two main types of productivity must be considered: annual overground production of shoots, and total annual overground production of organic matter (= shoots, litter and wood). The first concept relates to supply of feed for animals, the second mainly to possible supply of materials for soil improvement. Both are difficult to assess. Figures in the following are estimated from a few field observations and have been compared and completed from other sources (e.g. Gimingham, 1975).
Heather has a life cycle of 25-30 years, divisible into a stage of invasion(1-2 yrs), one of establishment (3-10) and a main one of high, almost constant shoot-increments (11-25) before the final degeneration. During its life heather increasingly sheds leaves and twigs until litter productivity exceeds that of shoots at about 25 years of age. To the produc-

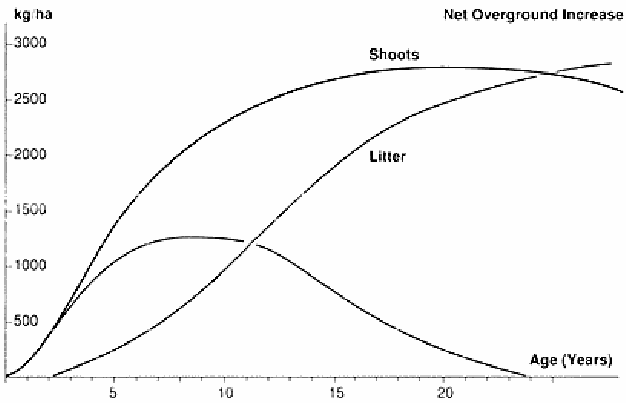

***Figure** 3. Assumed productivity of heathland per ha. Figures partly after Gimingham (1975)*

tion of shoots should be added that of woody mass. Data on this are few, roughly it seems to be about 400 kg/yr during the years of high productivity (11-25)

The productivity is decisive, when assessing the areas necessary to supply the quantities of heathland materials utilised. In general, the area required depends very much on the age necessary for obtaining a specific quality. High contents of woody material is found in old heather especially, tender shoots from young plants. Shoots for feed are produced at a rate of about 2,000 kg/yr from plants 5 to 15 yrs. old, heather fuel is accumulated at about 30,000 kg during a period of 25 yrs - to give a few examples.

In Table 6 the estimated requirements in 'hectareyears' are given for the heathland-materials mentioned in the foregoing. Following figures have been used for the estimates: Feed and fodder: 2 tons/ha/yr and 1 FE = 6.5 kg of heather: *træk-* used for litter in cowshed and in soil-fill: about 30 t accumulated over 25 yrs (~ 1.2 tons/ha/yr). Woody materials for 'fine' fuel etc: 0.4 tons/ha/yr. If amounts are derived from Figure 3 some divergencies can be noted. Total amount of litter accumulated over a full life-cycle amounts e.g. to about 38 tons. Because of losses from decomposition etc a figure of only 30 tons have applied in preparation of Table 6 The most 'expensive' use of the heath area seems to have been grazing/browsing, and - though more tentative - the use of træk and other soil-improving materials.

Sustainable use?
If all uses are considered (see Table 6), about 25-30 ha were annually 'harvested'. Against a backdrop of 270 ha available this may not seem alarming. But the specific demands for older types of heather create problems of sustainability. 'Area-time' for total regeneration requires about 185 hectare-years. The last estimate may indicate that some materials were actually soil-mined (as e.g. *træk*, soil-fill, mud etc.) - though they in Peder Knudsen's time were considered 'eternally available'.

Two interpretations of the situation can be offered, though based on weak estimates: 1) Peder Knudsen's use of the heathland approached ecological balance and was a well integrated part of his farming system, 2) The heathland was simply used as intensively as available labour technology permitted at the time. In either case the heathland seems to have been thoroughly used, and was not just 'left over land'.

To clarify the problems further observations on time for regeneration and for soil improvement are needed.

Export from the heathland
The main function of heath utilisation was no doubt attached to the role of heather as a kind of matrix material for mixed manure, so vital for preindustrial heath cultivation. This is evident from the 'exports' from the heathland (Flows B, C, and D of Figure 2 and 4). The flows are tabulated in the back to facilitate comparisons. It is difficult to estimate contents of soil-fill, since organic matter varies so much. Here organic contents have been set either at the level of træk or at only 2% for additional soil.

The total mass of the 'export' from the heathland is surprising: over 210 tons/yr carried away, but it should be noted, that much of it is either mineral soil or 'woody matter', mainly carbohydrates. Nitrogen is only a modest quantum, and especially the quanta of P and K are small. The role of heath materials as 'soil fill', as absorbing media, and as a supplement to the nutrients from the meadow is clear.

III. The cowshed and farmyard

The fenced-in areas, where animals were kept, encompass besides the cowshed and farmyard also some pens in the heathland. The possibility of pens in the heathlands has been disregarded in the following.

Most important was the cowshed/stable, where cattle and horses were kept from about mid-October till early May. The low, brick-walled and straw/heather thatched buildings were in the first place a climatic screen, protecting the animals from the wet, windy and cold Danish winter. Also the large, square farmyard (>500 m^2) surrounded by four wings of farm-buildings was well sheltered, at least from wind. The farm was located on high land near one of the small side-valleys to Haderup River, with direct access to the meadows in the valley of the river. This arrangement allowed cows and bullocks to come to the farm daily during the summer-grazing period the former to be milked, the latter to keep company and to be trained. While cattle were stabled for the winter, sheep were only on exception brought from the heathland into the farmyard/stable for protection and feeding.

Function

Both cowshed and farmyard - partially also the outfield pens - served as more than just climatic shelters. They were areas where fodder was processed into dung and from where the dung could be collected. For that purpose both cowshed and farmyard were paved with cobblestones to be almost impenetrable to liquid manure. In addition all the floors were kept covered with træk, brought in during late summer and supplemented with additional træk or heather as needed.

The most important functions within the cowshed/stable should not be forgotten: they were at least three in number. Firstly, it was a place of biological production, where raw fodder materials were converted into useful products for the farmer: milk, meat and labour energy. Milk was a basic foodstuff for the farm, both for humans and animals. Further, in Peder Knudsen's farm, the sale of animals (specifically bullocks trained as draught animals) was a main source of income. Secondly, it was the power station of the farm. The horses and bullocks were kept there, one team of each; quite a large number of draught animals, considering the area tilled per year. The draught animals were, however, necessary to cope with the huge demand for transport: horses supplied the bulk of the energy with bullocks providing the difference. Both were a steady power at low-cost fodder, especially the bullocks. Thirdly, the animals were producers of dung, essential for sustaining and increasing soil fertility. In fact the livestock composition was given much thought and attention. Cattle had as ruminants the main röle in dung production as well as in supplying dairy products for the farm population.

During the stable-feeding period the *træk*-cover functioned as a napkin-like material, absorbing and becoming an integral part of all manure produced. At intervals the saturated *træk* was shoved into the aisle and brought into the midden. (A similar process is well-documented in a highly developed form from the German *potstall* system). Similarly, the *træk* of the farmyard absorbed and collected all dung falling there.

Though of much less importance the sheep-pens of the outfield served the same purpose when sheep gathered in the pens for the night.

The reason for delving in detail with the dung-collecting system is its central röle in heathland farming as a vital source of material for fertilisation and soil improvement, e.g. by converting celluloses into humus-forming components.

Efficiency

The efficiency of the system cannot be evaluated directly from the diary and is therefore difficult to judge. No doubt a high percentage of all dung was collected, including the liquid part, and most of the fertilising elements thereby retained. To this end the almost impenetrable floors were invaluable. Airborne losses were inevitable, but diminished by using little volume in stall-buildings. Heavy ammoniacal smells were hence sure signs of heathland farming of the time! Still, the losses of fertilising elements are difficult to estimate, but no doubt relatively small.

With the background provided, it is tempting to see the function of the livestock/-cowshed unit as a provider of 'catalytic materials' for the cereal production of the farm as an important element. The inputs and outputs of the converter unit are reflected in the Table on Flow E (page 65).

Materials leaving cowshed/farmyard.with products.

All stall-fed livestock are have had their basic needs covered during the stall-feeding period of 195 days. To the need for basic fodder should then be added a contribution to 'production'. Horses were probably mostly idle all of the winter season. Production was then as shown below.

Production of milk and biomass:

The 825 kg increase in biomass corresponds to about 1200 FE, making the total value of production about 1500 FE. Amounts of NPK used in this production are mainly bound in the dung; total amounts exceed N: 251, P: 31 and K: 388 kg (for details: see Table 11). All these potential plant nutrients were largely in an available form. (Flow E). The following should be noted: Inputs of fodder materials have been estimated low -as 'just sufficient'. They correspond to the contents of the fodder from meadow, heathland and field. Inputs of bedding materials, litter, correspond to outputs from the heathland. Outputs of milk and meat as well as contents have been difficult to check. Finally, outputs of dung are those used in section 'midden'.

Bullocks= weight increase 3 x ~75 kg	225 kg
Cows: 3 x 2.5 litres milk per day in 195 days/yr, rest for calves. (~ 300 FE at 5 litres/FE).	1465 litres
2 calves born and fed for195 days/yr, weight gained 50 kg each	100 kg
Young cattle: weight gained 100 kg per animal	500 kg

IV. The Midden

Situated in the large farmyard, the main midden was impervious with its cobble-stone floor. Placed close to the cowshed, it was a place for storing dung, but also where dung was turned into mixed manure for later transfer to the (in)field. The main midden could be duplicated, or extra, smaller ones made to supplement it. Sometimes field middens were made at the place for their final use, a useful strategy to avoid leaching.

The midden was in many ways the hub of Peder Knudsen's farming system. Since it served as a storing place for the dung continuously produced during the stable-feeding period, it was designed to preserve precious nutrient-rich materials produced until their use in the field, keeping losses at a minmum. Consequently, the midden had to be leak-proof and reduce gaseous losses at the same time.

Handling of dung was seen an important task by Peder Knudsen. Care was exerted to keep losses at a minimum (cfr. construction of cowshed /farmyard). Gormsen (1991) gives a fuller description of practices in handling from which only a few main features shall be excerpted.

Three types of manure heaps have been reported, of which two, the farmyard and the field middens, must be characterised.

The farmyard midden.

This was a type of midden maintained through the regular cleanings of the cowshed during the winter. These were collected outside the cowshed until they were mixed with *træk* and some soil into one or two farmyard middens. A couple of smaller manure heaps seem to have been made during the winter, but the big mass of material was left for treatment until summer, when also the *træk* from the farmyard was added.

The manure heap itself comprised a bottom-layer of sods upon which alternating layers of dung and *træk* or soil-fill were stacked, with a top cover of soil. The 'soil' compo nent could stem from the toplayer of a ploughed piece of heathland, of mud or other type of soil with high organic contents. Usually there were 4 layers of dung (of 20-25 cartloads each) and 5 layers of soil/træk (of 60-70 cartloads each) in the midden, making together a heap of impressive dimensions: about 20 x 8½ x 2 m (~ 340 m^3).

The heap previously mentioned contained 70 cartloads of dung and 230 loads of soil/*træk*. Most often two smaller winter middens of only 100-200 loads each were establis hed. These were somewhat poorer with only 3 layers of dung to 3 of træk and 2 of mud - not so rich in nutrients, but still with high organic contents. Total contents of the midden heaps could easily surpass 600-700 cartloads: one of 70 + 230 loads and one or two of 100-200 loads added.

The field manure heaps. (See also materials for soil improvements above) Whether these were additional, differently located middens, or just farmyard middens re-moved is unclear. Usually, however, the field-heaps were made during the summer in the field to be manured for next spring's barley, usually one or two, each of 300-400 cartloads.

If these heaps were farmyard middens mixed and moved into the field, their volume seems to have been increased by added material. Some soil would normally be admixed, possibly also additional *træk*. One midden described must have contained 380-450 cartloads or about 130-160 tons of compost, but any opportunity to add extra was no doubt used.

The ash heap was mainly made from the burning of heather turves for heating the house. The ashes were often mixed with sheep's dung and used e.g for potatoes. Another type of *ash heap* was made in a presumptive field area in the outfield. In some cases dung was also added (21 loads of dung to 28 loads of træk to 35 loads of ashes from burnt turves). An overview of manure sources is given in Table 10.

The production of manure reported was thus based on inputs from both cowshed and heathland. From the cowshed came some 300 cartloads of manure, including what was originally some 70 cartloads of træk. An added import of 300 cartloads of soil with as much træk or other organic filling stuff (humus, humiferous soil, mud, bog) was used for a mixture that should result in an enriched sandy mould.

Flows through the midden
Imports to the midden consist of two flows (C and D). As previously mentioned, the distinction between these may be slightly artificial, but their constituent parts may have varied as well as the time for their collection.

Whether 'additives' were *træk* or bedding, or *træk* or soil, is significant in terms of organic contents (from 2-5 to about 50%). Still the major part of available plant nutrients occurs in the dung component.

Tables Flow E and F indicate the added matter originally passing the cowshed/farmyard as found from estimates; but much may have been lost later, notably N-containing gasses. Clearly, the dung conveys fertilising elements but also other content, specifically 'organic matter', which is important for soil improvement, must be regarded. The total amount exported, according to the Table, amounts to over 240 tons, but much of its N-contents may have disappeared, notably as gases. Solid parts account for half that much of which organic matter is probably only about 85 tons.

Compared to modern equivalents, Peder Knudsen's mixed manure resembles the enriched soil composts used in hothouses rather than 'real fertilizer'. Concentrations of plant nutrients are quite low in the manure, but the total organic matter is high enough that the compost deserves to be called 'soil improver'.

V. The fields
Peder Knudsen tilled three types of fields, of which two have already been reported; namely the fields in the high parts of meadow and the temporary swidden fields in the heathland. The first type mainly produced the oats for the horses, and the last type rye, probably for the market. These specific uses make it difficult to get information on areas tilled and yields gained. Fortunately, both types hardly use much of the manure, on which so much productive effort has been spent. The swiddens used much of the sheep's dung , sometimes supplemented with mud or ashes - especially after the 30es when potatoes were grown.

Use of the field
The main area to be tilled and manured was the infield. Its area was registered: to about 30 ha (55 tdr.) land, but its use in detail has only been discovered through analyses. To determine the annual use of the area, the diary is of assistance: the main rotation can be deduced from its information. The main cultivation seems approximately to have followed a 12 year cycle:

The rotation applied resembles the general 'two-course rotation' of that time, but the rotation was not strictly followed, and the various field units were without fixed limits. Thus the system belongs to the 'pasture-field systems' (Danish: *græsmark-systemer*. Frandsen, 1983). Their advantage was, that they allowed some flexibility regarding rotation - *in casu*: in the fifth year, depending on fertility, either rye or buckwheat was sown or the area fallowed. Also the rotation for a given piece of land could be shortened or extended to make full use of the manuring. The diagramme shows an 'average' condition of rotation.

1.	2.	3.	4.	5.	6.-12.
barley	rye	rye	rye	(rye)	fallow

Manuring took place in the autumn of year 12, and in the spring before the 1st barley was sown. The rye in year 2 was hence termed 'manure rye'.

If the rotation shown is used as a basis, some figures can be estimated for the use of the areas in general: Area sown/yr: 23 tdr. land. Fallow area: 32 tdr., barley: 4.6 tdr., rye: 9.2 - 13.75 tdr. Buckwheat would probably cover some 1-2 tdr., taken from the part of rye. Oats were generally not a part of the infield rotation, but mainly grown in the high parts of the meadow.

Yields
Gormsen (1991) found from the diary the amounts of seeds usually planted, and derived from this, assuming a reasonable use of seeds per td., that the areas annually sown were: Barley 3 tdr. land, rye: 16 tdr., oats 3 tdr. and buckwheat 1/4 td. From these figures, applying some traditional values for yield/seed ratios, annual yields have been estimated (Table 12). Because of its low grain-weight, the buckwheat area may have been slightly underestimated.

The rotational cycle was applied to some 6 'field units', meaning that 6 'mature' fallow areas were ploughed every year. Manure was only applied before barley was sown. In the autumn, before a first year barley parcel was ploughed, manure was applied, followed by another application in the spring with an additional ploughing. The last application of manure was the most substantial one, which often amounted to more than two hundred cartloads of mixed manure per td. land (or four hundred cartloads per ha) - corresponding to a layer of about 5 cm over the entire area to be sown. Buckwheat was usually sown to replace barley in the cycle in some field units, and in other places oats were sown instead of the fourth crop of rye. Potatoes were also grown, but mainly in the heath, outside the rotational area. Especially after the 1840s potatoes gained importance. They could be grown in outfield-heathland, usually only manu-red with sheep's dung, sometimes with a little manure added. Potatoes were usually followed by a crop of rye before fallowing.

From these considerations follow that only some 2 - 2½ ha were fully manured per year. This corresponds to at least about 400 cartloads of manure (or about 140 tons), which were in fact available. Over double the amount was used in some years (780 - 1200 cart loads). In the flow tables 600 cartloads, apparently a normal application, have been assumed.

If the inputs of fertilising elements (disregarding losses) from the cowshed/farmyard mentioned in the previous section are considered, the 2-2½ ha manured per year would be covered with mixed manure containing the following plant available nutrient elements (see Flow F): The lowest standard application of fertiliser via dung was apparently ~ 480 kg/ha of N, ~ 65 kg/ha of P, and 460 kg/ha of K. It should be remembered, that these amounts are excluding losses, nutrients made unavailable etc.

Nutrient balance of the soil

Even in relation to modern crop requirements, which for a 50 hkg/ha roughly are 130 kg N, 30 kg P, and 70 kg K on sandy soils, the dosage seems high, though losses are at play. In modern agriculture losses in the stable may exceed 50% of N, and lower, variable losses of both P and K. Losses of P and K were presumably small on Peder Knudsen's land, but only guesswork applies in estimating losses of N. Losses of N in relation to microbial activities are no doubt significant, but partly also beneficial in assisting decomposition of woody matter and in increasing pH. Losses of P and K are probably mainly from chemical fixation.

A different estimation can be carried out, based on the volume and contents of the farmyard middens. These consisted of 4 layers of dung encapsulated in 5 layers of soil or *træk*. Each layer of dung contained 20-25 cartloads, and a layer of træk of 60-70 loads, totalling 380-450 loads, each of 350 kg, or 135-160 tons. The contents of N, P, and K can be estimated from analyses of chopped up træk and of cow dung. Again it has unrealistically been assumed, that no losses of N, P, K took place since the mixing of the compost. From these assumptions follow that NPK contents amounted to:

N: ~1.1-1.3 tons P: ~80-100 kg, K: ~140-175 kg

If the analysed contents of *træk* with no addition of dung are used as a basis for calculation the following figures are found instead:

N: ~ 0.9-1.0 tons P: ~ 45- 80 kg K: ~ 220-260 kg
or
N: ~ 360-430 kg/ha P: ~ 18-35 kg/ha K: ~ 88-113 kg/ha

Even these figures are high, but are based on a situation resembling practices on Peder Knudsen's farm, so they probably represent a good approximation. The worst source of error, however, is much the same, namely that specifically the contents of N and K vary widely in cow's dung, both in relation to fodder and to the 'age' of the dung - in part due to heavy evaporation of N-gases.

The yields of the various crops can not be found from the diary, but have instead been estimated from the reported use of seeds and assumed coefficients yield/seed (Danish: *fold*. 'seed multiplier) from various sources. The yields seem low, but other contemporary sources report similar low yields from heathland areas (Table 9). Amounts fed back into the cowshed are given in table 'Flow G'.

If yields were modest, so were their resulting harvest losses. When these losses are related to the area harvested, the following figures are found:

Harvest losses:
N: ~ 35 kg/ha, P: ~ 4.7 kg/ha, and K: ~ 39 kg/ha.
Similarly adduction:
N: ~ 325 kg/ha, P: ~ 30 kg/ha, and K: ~ 145 kg/ha

From the figures follow that a substantial surplus of nutrients has to be expected for increasing fertility.

The magnitude of the losses can be discussed. Regarding P it is known from experience, that utility decreases with dosage. At ~ 40 kg/ha/yr nearly 80% is withheld, at ~ 150 kg it is only about 35 %. From this it may follow, that the P-demand of the crops is covered. How much is saved in the soil depends on retention capacity. Similarly with K requirements, a certain 'luxury-uptake' seems to take place, which makes assessment of dosage difficult, but also prevents a very high lossfrom leaching. Finally, losses of N increase tremendously with concentrations. Usually more than 50% is lost at high doses. There is ample room for losses of that magnitude, but the real ones were no doubt higher, because of the very low retention capacity. The crops used at Peder Knudsen's time would overdevelop stems at high doses of N; but this problem was never recorded.

Of great importance was the high volume of organic, 'woody' material deposited in the soil of the field, since it amounted to more than 30% of the total adducted materials or roundly 120 tons. Mixed into the ploughed top layer (25 cm thick, weighing some 1200 tons) of the two ha manured per year, this material would initially increase the organic contents of 10 % for the field with an impact on both nutrient- and water retention capacity. How much the initial percentage will be reduced during the rotational cycle must be left for guesswork.

In the preceeding text and the tables in the back, main features relating to the flow of matter through Peder Knudsen's farm have been described and some rough estimates of quantities made. Clearly such an approach was only meant as a first approximation. The losses, mentioned in several places, remain unknown and significant. They are, in fact, decisive for the total outcome of the farming strategy.

The Field Experiment

Peder Knudsen apparently exerted great care and used much work to avoid losses by the nutrient transfer process. Experimental observations of these losses would therefore be of interest, the more so since the transfer system probably reached its highest development at the time of Peder Knudsen, which generally was at peak for preindustrial, ecologically self-sustaining farming.

A field experiment at 1:3 scale applying functionally, but not necessarily identical practices in the historical sense, was carried out 1992-94. The main aims were:

- to observe the effects on landscapes, specifically the heathland, of the various simulated farming practices of the time of 'original' heathland.
- to assess the flows of matter within the traditional farming system. One of the main goals was to observe the losses by the nutrient transferring process i.e. the combined effects of using the heather-'napkin' system and the resulting absorption, deconcen tration and decomposition from mixing manure in Peder Knudsen's way.

Because the experiment from various reasons was left unfinished, observations were relatively few and only on short-term effects. Some of these related to effects on the cultural landscape, specifically the heathland, of the practices applied. Another set of initial observa tions describe one of main flows of the farming system, namely the flow from cowshed to midden to field.

Effects on the cultural landscape were deduced from observing changes of the heathland according to uses: browsing, burning, cutting and 'peeling' of *træk*. This last process, the peeling of *træk*, had the strongest impact on heathland, as many more years than the duration of the experiment would be required for a regeneration of the vegetative cover. An alarming effect was the tendency for creation of drifting sand. Also burning had a remarkable impact, leaving totally bare soil that was revegetated by slow invasion from the surrounding vegetation. Mowing of heather rejuvenated old plants to variable degrees, and grazing/browsing could slow down the degeneration of old heather vegetation, but was often insufficiently to regenerate healthy growth. Browsing by sheep seems to reveal a lot of preferences/avoidances. Most of the observations mentioned are not unique, and have been made also in other places, e.g. on the nearby Hjelm Hede (reported i.a. by Riis-Nielsen). See also S&N 1991. The goal of the experiment was to get an impression of the physiognomy of the historical heath-landscape, but this was prevented due to significant atmospheric transport of nitrogen-compounds (~20 kg of N/yr) and also attacks of the heather-borer, *Lymaea*.

The other part the field experiment comprised an attempt to follow the flows of matter through the system and the building up of an improved soil in the infield. The main flow from the meadow (feed) and from the infield (fodder) to the stables-farmyard-midden unit, in which animals change the fodder into dung, was simulated for almost two years. During these an auxilliary flow of *træk*, soil and other fillers were turned into mixed manure spread on the infield, which should result in a fine compost. Observations of the two streams mentioned aimed at allowing a quantitative assessment of the main elements transferred to be made, together with some of the effects of the transfer.

The first part of the transfer operations, producing the mixed manure from a set of livestock, similar to and fed ad *modum* Peder Knudsen, was carried out and preliminary assessments made. Subsequent use of the manure in the (in)field was unsuccesful, although this link was primarily geared toward clarifying the genesis of Danish 'plaggen'-types of soil, quite apart from the broader goals of observing effects of the ensuing soil-improvement. These questions remain largely unanswered.

Summary and conclusions

The functions of Peder Knudsen's farming have been described on the basis of available information, mainly from his diary as given in Gormsen's studies (Gormsen 1982 and 1991), with additional information from maps and registers. Modern data plus a few analyses have been used in an attempt to assess land use and productivity of areas and animals.

It is believed, that the estimates arrived at, though of little accuracy, together help create a general idea of the functioning of the farming system. Of specific interest are the operations by which plant nutrients were moved from the meadow to the infield via the cowshed and its livestock, decisively assisted by a series of flows from the heathland. The general flow, depicted in tables A - G and in Figure 4a and b, reveals that spectacular quantities were deposited in the (in)field every year, though it must be underscored, that losses from evaporation, leaching, surface run-off, decomposition etc. have been impossible to estimate. Nonetheles an ongoing enrichment of the tilled soil from adducted organic material must have taken place. The quantities of N, P and K were so large that an improving effect most certainly was felt, even leaving generous margin for inevitable harvest losses.

Some of the general questions raised on the specific type of infield-outfield applied by Peder Knudsen are related to:

- the function of the various elements of heathland farming.
- the nature of the synergy between functions of the elements, leading to e.g. an understanding of the relationship between area type and size, as well as number of livestock.

Answers to the questions have been provided inasmuch as :

-the flows connecting the various elements in Peder Knudsen's system have been identified, and their mutual interdependence has been pointed at.
- the dimensions of the flows have been approached.

Based on such observations the most important linkages within the system seem to include the following.

1) Productivity of the meadow was seen a major limiting factor for the number, size and yield of livestock, specifically the ruminants. The meadow was used to contemporary capacity.
2) Livestock functions - directly dung production in terms of quality and quantity, but also transporting capacity - were a limiting factor for the harvest yields of the infield.
3) Manuring practices, dependent on additives from the heathland, greatly influenced the net transfer of fertilising elements to the field and hence its yields. Use of *træk* played an important role in conservation of nutrients by absorbing and de-concentrating elements. The dung no doubt influenced the decomposition of nutrients from *træk*, and accelerated forma tion of humic matter (cf. modern use of ammonia on straw), but the heathland delivered the basic materials for lasting soil improvement. The heathland seems to have been used to capacity at the technical level of that time.
4) The combined effects of points 1) to 3) were decisive for solving the soil fertility problem by increasing retention capacities for plant nutrient ions and for water - and hence also for the yields and stability of cereal production.
5) Cereal production - though with relatively modest yields - amplified possibilities for supporting livestock, both ruminants and others (e.g. horses), which increased efficiency of transportation and diversified production - by increasing possibilities for full utilisation of the meadow and heathland potentials.
6) General applicability of a rule 'fixed proportion of meadow area to heads of cattle', and hence a strict relation (a 'gearing') of meadow to cultivated acreage can not proven, though such a relation seems to have been perceived by Peder Knudsen. A functional limitation existed both regarding the relation meadow/heads of cattle and cattle/cultivable hectares of field, but both relations depend on kind of technique applied, e.g. regarding effectiveness of the handling of manure. The refined handling of dung/manure has - apart from a few exceptions (e.g. Stoklund 1990) - not raised much attention in reported Danish research.
7) The enormous transportation demands in Peder Knudsen's system was a serious tax on draught animals and work force, but was made tolerable since much transport took place in the off-season to cereal production.

The points 1-7 above all indicate, that an appreciation of Peder Knudsen's farming requires an insight in the interactions constituting the farming system. As shown theoretically by Rasmussen (1979) the infield-outfield system has a capacity for increasing the combined utility of in- and outfield. Peder Knudsen's farm is no exception to that rule, and goes further to demonstrate that the farm work force (human and animals) is, if not decisive, then at least an important limiting factor for the total utility of the system.

Evidently, the accuracy of the flow assessment is doubtful: the amounts are not given in detail every year, so figures believed to be representative have been used. Amounts are given in cartloads, a very approximative measure etc. Yet there is a certain coherence in the findings of this analysis of flows, indicating that some generalities prevail. A few of the general findings shall be mentioned (see Figure 4a and b).

The conspicuous volume of total transports merits comments. From the meadow over 10 tons (Flow A) were every year transferred to the cowshed, where they met with about 100 tons (B and C) - or often over 200 tons (B,C and D) - originating from the heathland. Whereas fodder stemmed from the meadow and the (in)field (~10.000 and ~24,000 FE respectively) (see A and G), the great mass of organic materials for soil improvement came from the heathland (2.5 versus ~ 6.5 tons).

Regarding contents of N, P and K, the heathland contributed, except for N, about the same amounts as those from the meadow to the cowshed (Figure 4a and b): ~ 650 kg N,

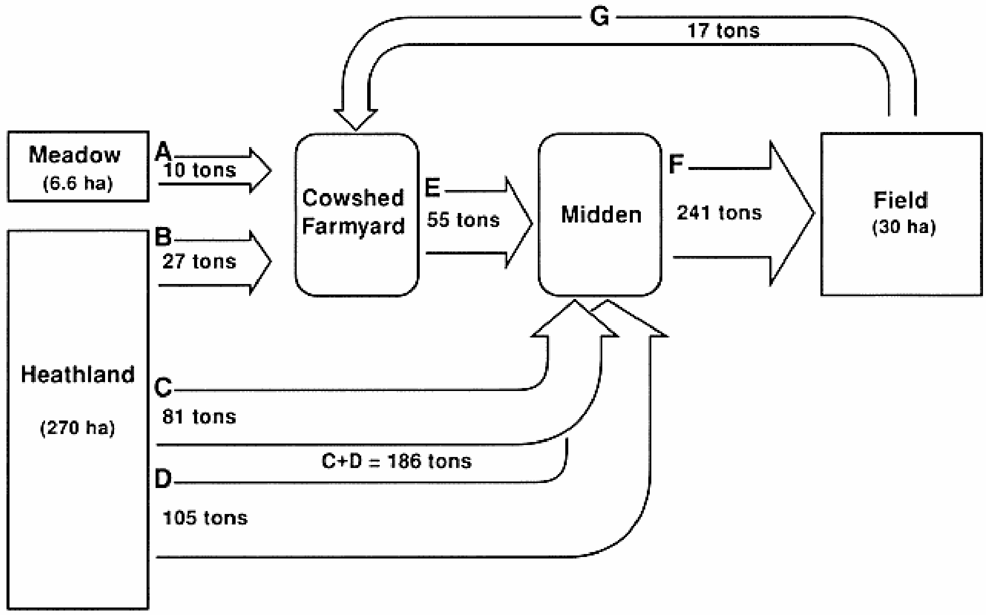

Figure 4a. Flows in Peder Knudsen's farm in tons/year.

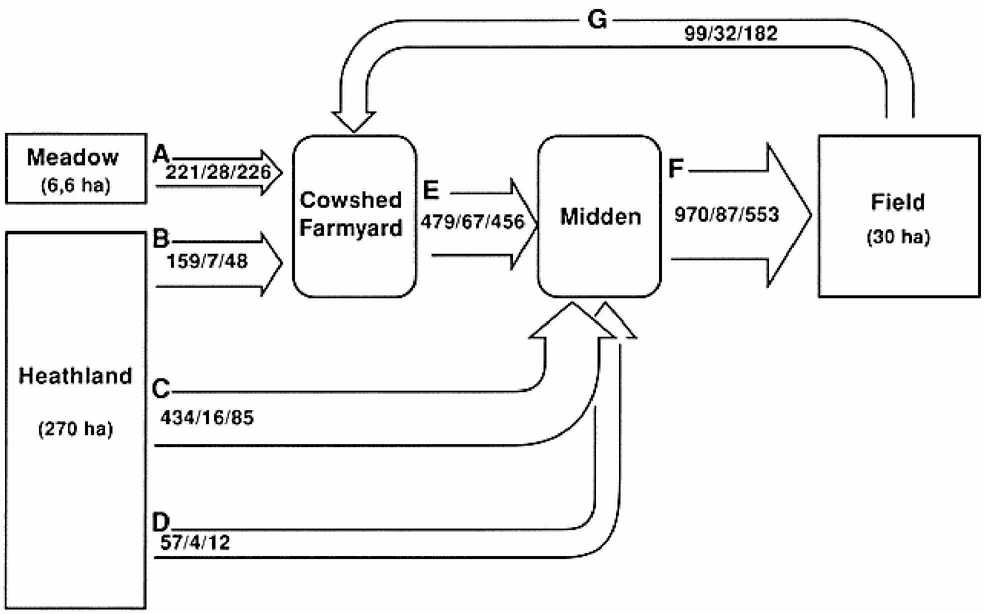

Figure 4b. Flows in Peder Knudsen's farm showing amounts of N, P and K shown in that sequence.

~30 kg P and ~145 kg K (Flows B, C and D added; træk used for soil fill). This should be compared to supplies from the meadow and infield of ~220 kg N, ~30 kg P and ~225 kg K.

It must be noted that plant nutrients in heathland materials were much more strongly fixed and thus less available than those of the meadow. Beginning in the cowshed , decomposition gathered speed in the midden and field, probably catalysed by ammonia-compounds released by microbial processes. If this is true, the significance of the meadow was perhaps just as important as a source of catalysts than readily available fertiliser. The farming system most clearly belongs to the group of 'concentrational' agriculture. However, plant nutrients were concentrated both from transfer from one element, the meadow, as well as during transfer from the heathland.

The losses from dung and mixed manure were no doubt conspicuous- even more so when dealing with N-containing materials than the two other considered considered (P and K). Most of the altter two were transferred with the organic ('woody') materails from the heath. Soil quality was improved due to the fact that up to 400 tons of enriched materials were mixed into only about 2-3 ha of annually tilled area. Even now , more than 150 years after Peder Knudsen's activities, his former infield requires about 50 kg of NPK-fertilser less per ha than the surrounding areas.

The cost of the improvement was high: almost 300 tons (not including water contents) to be carted from the outfield (meadow, heathland) to the cowshed/farmyard, and from there to the outfield. And the reward was relatively modest: crops of cereals (~2 tons/ha of barley etc.), though with a marketable surplus, to which should be added most materials for subsistence, including milk and occasional meat. It should not be forgotten that a general intensification of land use combined with improved crop security were parts of the improve ment.

Altogether the farming system served its purpose: to solve the problems of poor soil quality by a strategy of concentration and conservation. The low concentrations of chemical elements in the constituent parts of Peder Knudsen's compost prevented high losses of nutrients, but also demanded high labour inputs. The system thus differs essentially from the strategy of modern agriculture.

Apart from an initial demonstration of the main features of Peder Knudsen's farming system as an intricately balanced composition of areas, their uses, animals and practices, the description of quantitative properties of the farming is only approximate. Especially two areas need further investgation:

- the efficiency of the specific plant-nutrient transfer system: meadow, cowshed, midden, infield (assisted by the 'napkin'- practices using heathland materials); and
- the effects of the system on soilimprovement and its long-term effects on water and nutrient retention capacities.

The two areas mentioned represent just some of the most prominent challenges, requiring long-term experimentation (> 10-15 years). Yet they remain important, alone for the reason, that Peder Knudsen's practices can be seen as comprising some interesting solutions sought by the modern sustainability project. The historic system may represent one of the least polluting available, yet unfortunately also one of the most transport-intensive.

Research was funded by the Ministry of the Environment and the State Research Council for Science, and was supported by and located at the Hjerl Hede Frilufismuseum. All efforts of support and assistance, including inspiring discussions in a quorum of interested persons, are hereby gratefully acknowledged . Because of unforeseen difficulties e.g. with the available area, the experiment had to be discontinued; hence proven conclusions from this are few and have generally been omitted from this presentation.

Tables and the list of references on pages 60-66

Tables A : Tables describing the farming environment - Tables 1-3.

Table 1. *Sub-soil particle size distribution in soils around Staulund. Figures in dry weight %.*

Locality Sample numbers	Kongenshus (9)	Høgild (58)	Høgild (65)	Høgild (95)	Gindeskov (7)	Gindeskov (103)	Gindeskov (15)
Coarse sand	73.9	66.9	65.2	62.4	85.4	71.2	36.0
Fine sand	26.1	31.0	31.7	26.1	13.9	24.4	63.3
Silt	0.1	1.0	1.4	6.3	0.2	4.4	0.5
Clay+silt	1.3	2.7	4.7	1.1	6.7	5.2	1.1

Source: Køie (1951); 108 ff. sample no. referring to Køie's primary table.
Kongenshus is located abt. 5 km, Høgild abt. 3½ km east of Stavlund, and Gindeskov less than 1 km south of Stavlund.

Table 2. *Soil profile from Peder Knudsen's heathland area. (Coll. 1994).*

Depth cm	C %	Humus %	CEC	H^+ ----------	K^+ meq/100g	Ca^{2+} ------	N %	P total mg/kg
0-5	0.87	1.49	2.82	0	0.06	2.34	0.05	1862
5-10	0.84	1.45	3.27	0	0.09	2.81	0.05	1767
10-15	0.85	1.47	3.46	0	0.09	2.91	0.05	1529
15-25	0.66	1.13	5.28	2.66	0.04	2.26	0.03	1069
25-30	0.32	0.55	4.07	2.36	0.09	1.28	0.02	178
30-35	0.29	0.51	6.54	5.48	0.03	0.78	0.02	85
35-40	0.20	0.35	3.39	1.77	0.05	0.39	0.01	0
40-45	0.15	0.25	1.89	1.35	0.05	0.31	0.01	0
45-50	0.12	0.21	1.88	1.16	0.05	0.49	0.01	0

Note: The units given for here P correspond to units in ppm or g/ton, and values for K multipied by 40 correspond to units of g/kg used in text.

Table 3. *Mean monthly precipitation (mm) and mean temperature (C°). Herning* 1886-1925.*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yr
mm	59	44	50	43	44	49	65	94	67	76	66	72	730
C°	-0.1	-0.3	1.5	5.4	10.7	14.1	15.6	14.7	11.4	7.4	3.5	1.1	7.1

*) Herning is located about 23 km south of Staulund.

Tables B: Describing features of Peder Knudsen's farm, Tables 4- 12.
Note! Figures in the following tables have not been rounded to diminish cumulative errors from adding/multiplication.

***Table 4**. Estimates of daily fodder needs per head in FE = Fodder Equivalents of 1 kg barley.*

Animal	Horses (2)	Bullocks (3)	Cows (3)	Young cattle (5)	Sheep (50)	All livestock
Live weight	600 kg	450 kg	400 kg	100 kg	(40 kg)	4,250 kg
Basic fodder	4.5 FE	3.75 FE	3.5 FE	2.0 FE	(0.3 FE)	40.8 FE
Extra fodder	2 - (summer)	1.5 - (summer)	2.5 (all year)	-	-	16.0 FE

Source: L.I. (1989). Fodder requirements are estimated from those of modern cow, modified in proportion to live-weight 'historical cow'/'modern cow'. Sheep not included in total.

***Table 5**. Estimates of total output from meadow based on various assumptions.*

Diary on hay harvest for winter consumption	29 cartloads ~10.2 tons	8.1 tons d.m. ~ 5,500 FE > 11,000 FE/yr
Modern productivity	4.9-6.9 tons d.m.	~ 20,000 (-28,000) FE/yr
From fodder requirements	~ 20,000 FE*)	~ 13,5-14,000 FE/yr

*) The figure includes contributions from barley and oats (grains + straw): ~ 7,500 FE.

***Table 6**. Use of heathland materials per year and area/time for regeneration.*

Initial use	Place of use	Amount annually used	Dry weight of material (tons)	Area used annually (ha)	Age of heather used(yrs)	Total meeded
Sheep browsing	heath	50 x 365 x 0,3 FE	35.6	18	1- 2 (shoots)	18
Sheep fodder, winter	farmyard	6 cartloads	2.1	1	1- 2 (shoots)	1
*Træk**)	cowshed	70 cartloads	24.5	0.1	60	6
Bedding	cowshed	3 cartloads	1.1	1	15-25	1
Midden soil**)	midden	230 cartloads	80.5	1.3	30	40
Soil-fill***)	midden or infield	300 cartloads	105.0	0.2	30	6
Swidden	outfield	no transport	(?)	2	30	60
Heatherf.fuel	ashheap	3 cartloads	1.0	0.2	25	5
Sods f. fuel	ashheap	70 cartloads	24.5	0.8	20	48
Total		700-900 cartloads	270 tons	~ 25 ha	years	~185 ha x yrs

Source for column 1-3: Gormsen (op.cit.). Compiled from Peder Knudsen's diary. Assumption: Annual accretion of heather, see Figure 3. Annual requirements in 'hectare-years', considering specific requirements for age of heather related to use.
*) *Træk* containing woody mass, roots and litter, supposed to be accumulated during at leas two life cycles, each 30 years or about 30 tons in 60 years. **) Midden-soil supposed to be 50% mineral soil and 50% organic materials, composed as *træk*.
***) Soil-fill assumed 5% organic contents, as if ploughed to 25 cm directly from a heath surface 15 years old.

Material	Amount (tons)	Value (FE)
Meadow hay	29 cartloads ~ 10.150	5,500
Heather hay	3 cartloads ~ 1.050	400
Grains (barley, oats)	~ 7.000	7,500
Straw (barley, oats)	~ 7.000	2,000
Total	~ 25.200	14,775

Fodder values from LI (1989): Specifically meadow hay, 1 FE ~ 1.84 kg fodder at 20% water contents. Estimated: heather hay: 1 FE ~ 6.5 kg

***Table7**. Fodder consumption during stallfeeding to the cow-shed/farmyard.*

***Table 8**. Manure produced per stable-feeding period (~ 195/365 year).*

Animal	solid dung per head*)	liquid dung per head *)	N total (kg)	P total (kg)	K total (kg)
Horses (2)	1.7 t/season	1.5 t/season	33.4	4.6	35.0
Bullocks (3)	1.4 -	1.2 -	41.0	5.6	43.2
Cows (3)	2.3 -	2.0 -	69.4	9.2	70.1
Young animals (5)	0.8 -	0.6 -	36.7	5.3	37.2
Total	~ 19.5	~ 15.6	180.5	24.7	185.5

*) Estimated from modern figures of all-year stall-fed cow with an intake of 5,000 FE/yr, assuming dung production proportionate to feed-intake and duration of stall-feeding (See Table 4). Figures on dung-production and contents based on LI (1989b) except for horses.

***Table 9**. Fodder and dung. Contents of NPK.*

Fodder origin	Fodder type	Weight (tons)	N (kg)	P (kg)	K (kg)
Infield	Grains + str*)	~ 7 + 7	94	31	133
Meadow	M. hay	~ 10	162	28	226
Heath	H. hay	~ 2	18	2	15
Total fodder		~ 17 + 7	274	61	374
Total dung	solid+liquid	~ 18 + 16	181	25	185

*) Straw only partly included. (- rye and buckwheat).

Table 10. Mixed manure per year. According to origin.

Type	Dung-mix (cartloads)	*træk*/turves (cartloads)	Soil-fill (cartloads)	Total (cartloads)	Total (tons)
Farmyard	70 (100)	230 (350)	200 (250)	500 (700)	175 (245)
Field heap	150	150	100	400	140
Ash heap	21	35 ashes	16 bogs	72	25
Total	91 (271)	265 (535)	316 (366)	972 (1172)	200 (410)

Figures refer to regular production; in parentheses: production occasionally added up to.

Table 11. Annual production from cowshed: Contents of NPK.

	N (kg)	P (kg)	K (kg)
Milk (1465 litres)	7.8	1.5	2.3
Weight incr.(825 kg)	31	4	3.3
Subtotal foods	~ 40	~ 5.5	~ 5.6
Dung (solid & liq.)	~ 181	~ 25	~ 185
Total products	~ 221	~ 31	~ 191

Table 12. Cropped areas within rotation, and estimated yields per year.

	sown area (td. land)	Stored seeds (td. seed)	tdr seeds per td. land	Sown area (td land)	Yield/seeds 'fold'	Gross yield (tons)	net yield (-seeds) (tons)
Barley	4.2 - 4.6	3*)	1 : 2	4 - 6	7 : 1	3.66	3.14
Rye	12.2- 18.3	8	1 : 2	14 - 16	6 : 1	9.75	8.13
Oats	4.2 - 4.6	42	1 : 12	3	6 : 1	4.01	3.60
Buckwheat	1.25-2.50	5/32 ~ 1/4	1 : 5	1/4	6 : 1 ?	1.50	1.25

Second column: Sown area from information on rotation. Fifth column: Sown area from volumes of stored seeding materials. Seventh column: Yields calculated from bushels of seeds multiplied by 'yield to seeds- coefficient'. Bushels converted to metric tons using following weight per bushel figures: barley 21.8 kg, rye: 25.4 , oats: 20, buckwheat: 10. Areas sown per year varied (in relation to soil quality/fertilisation?).

*) Gormsen (1991) has '8'.

C) Tables describing flow of matter (plant nutrients etc.) within Peder Knudsen's farm (ref. Figure 2 and 4).
Figures in the following tables have not been rounded to avoid cumulation of errors by adding/multiplication.

Flow A from meadow to cowshed.

Cowshed	Cartloads	Weight (kg)	FE	N (kg)	P (kg)	K (kg)	Woody m.(kg)
Hay	29	10,150	5,500	221	28	226	2,460

Source: 'Græshø' in L.I. (1989).

Flow B from heathland to cowshed/farmyard.

Cowshed	Cartloads	Weight(kg)	FE	N (kg)	P (kg)	K (kg)	Woody m. (kg)
Heather	6	2,100	~ 400	18	1.4	15	441
Træk	70	24,500	0	132	4.9	26	9,850
Bedding	3	1,050	0	9	0.7	7.5	220
Total	79	27,050	400	159	7.0	48.5	10,481

Heather assumed at 15% water. Contents: N: 0.90%, P: 0.07% and K: 0.87%. *Træk* contents: minerals 50%.
Of the rest: N: 1.08%, P: 0.04%, K: 0.21%. Bedding = heather.

***Flow C from heathland to midden.** Two alternatives shown as to composition of added material: træk or soil-fill.*

Midden	Cartloads	Weight (kg)	FE	N (kg)	P (kg)	K (kg)	Woody m. (kg)
Træk	230	80,500	0	434	16	85	32,360
Soil-fill	230	80,500	0	44	3	8.4	3,240

Contents of *træk*, see above. Soil-fill assumed at 5% organic contents, neglecting mineral contents of N, P and K (mostly unavailable to plants?). The values for *træk* have applied in the following.

***Flow D from heathland to midden or infield.** Case of extra 300 cartloads produced.*

Midden or infield	Cartloads	Weight (kg)	FE	N (kg)	P (kg)	K (kg)	Woody m. (kg)
Manure heap	300	105,000	0	57	4	12	2,100

Soil-fill here assumed at only 2 % organic contents, as at previously used infield area.

***Flow C & D from heathland for 'mixed manure' added*).** Contents of NPK.*

Midden/-infield	Cartloads	Weight (kg)	FE	N (kg)	P (kg)	K (kg)	Woody m. (kg)
Total	530	185,500	0	491	20	97	~6,125

*) These flows were normally added for the making of >mixed manure= . The high comtents of N, P and K are when using *træk* for fill; in parenthesis are shown case of the soil-fill alternative.

Flow E from cowshed to midden. *If losses are disregarded, the flow is the sum of flows A, B, C, D and G. Plant nutrient elements in materials used in cowshed. Contents of N, P and K.*

Material: Fodder	Weight (tons)	FE	N (kg)	P (kg)	K (kg)
Meadow hay	10.150	5.500	221	28	226
Heather hay	1.050	~200	18	1.5	15
Grains + straw (excl. rye)	17.400	8.600	98.6	32	182
Subtotal fodder	28.600	14.300	337.6	61.5	423
Material: Bedding					
Træk	24.500	-	132	4.9	25.7
Bedding	1.050	-	9	0.7	7.5
Subtotal bedding	25.550	-	141	5.6	33.2
Total	54,200	14,300	478.6	67	456.5

Heather hay: figures from Stålfelt (1970), meadow hay, straw (barley) and grains: LI (1989), Mineral contents of træk/bedding found from: N = 0.85% of dry matter = 0.85%. P = 0.44 g/kg, K = 208 ppm. Source; analysis. Heather hay: 6.5 kg ~ 1 FE. Meadow hay: 5.5 kg = 1 FE. Source LI (1989)

Flow F from midden to infield of mixed manure. *Flow F is the sum of flows E + C + D. Matter exported from midden cowshed/farmyard. Contents of N, P, and K.*

Material	Cartloads	Weight (tons)	N (kg)	P (kg)	K (kg)
Flow E	108 +	54	479	67	456
Flow C	230	80	434	16	85
Flow D	300	105	57	4	12
Total	638 +	239	970	87	553

NB: Losses of N, P, and K from materials disregarded. Number of cartloads averaged.
*) Dung: see table 9; mix materials: see Flow B.

Flow G from infield to farm (incl.cowshed). *Harvest, and contents of NPK in grains + straw.*

Crop	Area (ha)	Net yield t	FE	N (kg)	P (kg)	K (kg)
Barley	1.6	3.10	3,040	40.4	12.2	12.2
Rye *)	~ 8.7	8.13	8.050	83.7	24.2	32.2
Oats	~1.6	2.84	2,450	36.0	9.8	12.3
Buckwheat	0.3	1.10	1,100	11.4	3.3	5.5
Straw**)		10.50	2,333	10.8	7.0	151.6
Total	12.2	25.67	16.973	182.3	55.5	213.8
Total excl. rye	3.5	17.54	8.883	98.6	32.3	181.6

Contents in FE and of NPK, based on L.I. (1989).
*) Rye was not used for fodder. Amount of fodder-cereals was about 7 tons/yr.
**) Total harvest of straw: ~ 40 tons. Only ~ 10.5 tons were used for fodder.

References

Bath, B.H. Slicher van (1963): The Agrarian History of Western Europe ao 500-1850. Edward Arnolds. London.

Blicher, S.S. (1839): Viborg Amt. In: Bidrag til de danske Provindsers nærværende Tilstand i oekonomisk Henseende. XII Stykke. København.

Christiansen, S. (1978): Infield-outfield systems. Geografisk Tidsskrift, Danish Journal of Geography 77: 1-5. Copenhagen

Christiansen, S. (1996): Concentrational agriculture. Geografisk Tidsskrift, Danish Journal of Geography 96: 123-38. Copenhagen

Delfs, J. (2000): Heidewirtschaft. Plaggenhieb und Streunutzung in der Lüneburger Heide. in: Museums-dorf Hösseringen: Materialen zum Museumsbesuch, 33. Uelzen.

Frandsen, K.E. (1983): Vang og Tægt. Bygd. Esbjerg.

Gimingham, C.H. (1975): An Introduction to Heathland Ecology. Oliver & Boyd. Edinburgh.

Gormsen, G. (1982): Hedebonden. Studier i gårdmand Peder Knudsens dagbog 1829-57. 'Folk og Kultur'. Special issue of Årbog for Dansk Etnologi og Folkemindevidenskab. København.

Gormsen, G. (1991): Traditional heathland farming in Western Denmark. Etnologia Scandinavica 21: 105-125.

Hannerberg, D. (1972): Svenskt agrarsamhälle under 1200 år. Scandinavian University Books. Stockholm.

Hansen. K. (1976): Ecological studies in Danish heath vegetation. Dansk Botanisk Arkiv, 31 (2):1-118. Copenhagen.

Havskov-Sørensen, P. (1963): Malkekvægets Fodring. In: Rationelt Landbrug II. kap 36A: 3-23. Bjæverskov.

Højrup, O. (1970): Hedens udnyttelse. Danmarks Natur VII: 73-106. Politikens Forlag. København.

Jensen, Kr.M. & Jensen R.H. (1979): Kulturlandskabet i Borris-Sdr. Felding. Geografisk Tidsskrift, Danish Journal of Geography 78-79: 57 - 99.

Køie, M. (1951): Relations of vegetation, soil and subsoil in Denmark. Dansk Botanisk Arkiv, 14 (5):1-164. Copenhagen.

L.I. (see Landbrugets Informationskontor).

Lambert, Audrey M.. (1971): The Making of the Dutch Landscape. Seminar Books. London and New York.

Landbrugets Informationskontor (1989 a): Håndbog i driftsplanlægning. Århus.

Landbrugets Informationskontor (1989 b): Håndbog for kvægavl. Århus.

Landbrugets Informationskontor (1995): Håndbog for plantedyrkning. Århus.

Meteorologisk Institut (1933): Danmarks Klima G.E.C.Gad. København

Nielsen, L., Debosz, K. & Schierup, H.H. (1998): Extensive grassland systems : N-minerali zation, productivity and biodiversity. Grassland Science in Europe, 3: 315-318.

Odgaard, B. (1994): The Holocene vegetation history of northern West Jutland, Denmark Opera Botanica 123. Copenhagen.

Rasmussen, K. (1979): A mathematical description of an infield-outfield system. Geografisk Tidsskrift, Danish Journal of Geography 78-79: 5- 9. Copenhagen.

Riis-Nielsen, T. (1997): Effects of nitrogen on the stability and dynamics of Danish heathland vegetation. Unpublished Ph.D. thesis. Dept. of Plant Ecology. Univ. of Copenhagen

S&N = Miljøministeriet, Skov- & Naturstyrelsen (1991): Hedeplejebogen. København.

Stoklund, B. (1990): Tørvegødning - en vigtig side af hedebondens driftssystem. Bol og By, Landbohistorisk Tidsskrift, 1: 47-72.

Stålfelt, M.G. (1960): Växtekologi. Svenska Bokförlaget. Stockholm.

Troels-Smith, J. (1984): Stall-feeding and field-manuring in Switzerland about 6000 years ago. Tools & Tillage, V,1:13-25. Copenhagen.,

Uhlig, H. (1961): Old Hamlets with Infield and Outfield Systems in Western and Central Europe. Geografiska Annaler, XLIII, 1-2.

Weis. Fr. (1932): Fortsatte fysiske og kemiske undersøgelser over danske hedejorder og andre podsoldannelser. Det Kgl. Danske Vid. Selsk.: Biologiske Meddelelser. X,3. København