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Yield Responses and Nutrient Utilization with the Use of Chopped Grass and Clover Material as Surface Mulches in an Organic Vegetable Growing System

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ABSTRACT

Trials were performed with red beet and white cabbage in 1998–2001 to assess the effects on yields and nutrient utilization of surface mulch (chopped grass and/or red clover). No other nutrients were applied. Nitrogen (N), phosphorus (P) and potassium (K) contents were measured in mulch, saleable products and above-ground plant residues. A single mulch application of about 12 Mg DM ha^{-1} increased the yields of both crops significantly. Mean yields of saleable products were increased from 27 to 33, and from 44 to 56 Mg FW ha^{-1} of red beet and white cabbage, respectively. However, the average apparent recoveries of mulch derived nutrients in above-ground plant parts, calculated by subtraction of uptakes in the control treatment, were only l3, 14 and 18% of N, P and K, respectively. Some 3–10% of the N supplied in mulch was found as mineral N at 0–60 cm soil depth after harvest, and in late autumn approximately half of the P and all the K supplied was found as P-AL or K-AL (ammonium lactate and acetic acid) plus acid-soluble K in the topsoil. Mulch application also increased the yield level of spring cereals grown in the following year by on average 0.6 Mg ha^{-1}, or 20%.

INTRODUCTION

Surface mulching with chopped fresh plant material is practised by a number of organic vegetable growers in Scandinavia. The method supplies crops with nutrients and thus increases vegetable yields; it suppresses annual weeds,

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decreases evaporation and regulates the soil temperature amplitude. Further, it promotes faunal and other biological activity in the soil, increases the supply of oxygen to the roots and improves soil structure (Danfors & Linnér, 1994; Larsson *et al*., 1997; Magnusson, 2000). Such amendments are of special interest to growers with restricted access to farmyard manure. However, the method requires a considerable area for growing the mulch material, and may therefore be considered wasteful. For the surface mulch to control weeds efficiently, a soil cover of at least 5–8 cm green mulch is recommended (Magnusson, 1995; Larsson *et al.,* 1997), or repeated applications of a 3 cm layer (Jaakkola, 1995). Such applications represent a considerable amount of plant material, and the area required to produce the mulch may be as much as three times the size of the vegetable producing area (Jaakkola, 1995). Further, the efficiency of the applied nutrients may be questioned. In a Swedish experiment, a mixture of freshly chopped grass and clover was applied to broccoli twice during growth, containing about 600 kg ha^{-1} of both nitrogen (N) and potassium (K) (Magnusson, 2000). The amounts of N and K removed in harvested broccoli were only 10 and 12%, respectively, of the amounts added in mulch. The amounts in leaves and stems were 37% of the N and 70% of the K added in mulch. Hence, if plant residues are left on the field, the degree of utilization of the applied nutrients is low. The surplus N is prone to both leaching (Ekbladh, 1995) and gaseous losses (Janzen & McGinn 1991; Larsson *et al.,* 1998). However, it must be remembered that recycling nutrients through animals also incurs large nutrient losses during fodder and manure handling as well as ammonia (NH_3) losses directly from the animals.

The fate of the surplus nutrients is of interest in relation to nutrient efficiency and for recommendations of when and how much chopped plant mulch to apply in organic horticulture. What happens to the nutrients after application varies with the type, maturity and amount of mulch material used, with growing conditions such as precipitation, soil type and soil fauna, and with the nutrient under consideration. Most investigations so far have been on N. When mulch material with a low carbon (C) to N ratio is used, N is easily lost through ammonia volatilization and/or as nitrous oxides (Larsson *et al.,* 1998). Leaching is also more likely to occur from material with a low C/N ratio, whereas the use of mulch with a high C/N ratio may cause N immobilization in soil (Larsson, 1997). To achieve increased yields, a low C/N ratio is usually considered necessary, despite the associated risks of N losses.

To our knowledge, no investigations have focussed on the fate in soil of phosphorus (P) and K surpluses from chopped plant mulch. As K in plant material is readily soluble in water, it is easily transported into the soil by precipitation, where it may be available for plant uptake, subject to fixation on clay minerals, or even leached from light textured soils. Water-soluble P in the mulch may be transferred to soil as described for K. Drying of the plant material may increase the fraction of water-soluble P. Jones & Bromfield (1969) found that 70–80% of the total P content in grass and clover plants that had wilted in the field was water-soluble. Of this P, 70–90% was present in inorganic forms. At the same time, or alternatively to the leaching that may occur, the mulch is decomposed by fungi and bacteria that assimilate P. During this process, the fraction of organic P in the plant residues may increase temporarily (Lockett, 1938; Kaïla, 1949). However, for plant residues with a P content above 0.2–0.3%, mineralization of organic P will readily occur in soil (Singh *et al*., 1992), in close correlation to that of N, as shown for example by Timm *et al.* (1980). Hence, the P applied in plant material may be readily available for plant uptake, as shown in maize where the P uptake from brewer's hops was larger than that from soluble inorganic phosphate (Dalton *et al*., 1952), and in ryegrass where dry matter yields and P uptake were larger when young barley leaves were applied to soil than when soluble inorganic P was used (Fuller *et al*., 1956). These authors suggest that the mineralization of P was well synchronized to the plant demand, and that the inorganic P from plant material may have been less readily adsorbed to oxides in soil than was the soluble P from mineral fertilizer.

Most of the N applied in chopped clover mulch is obtained by fixation from the atmosphere, and is thus not derived from the soil on which the clover was grown. In the case of P and K, chopped plant mulch involves the movement of nutrients from one area of the farm to another. It is therefore of interest to study the implications of this practice for the efficiency of the system as a whole. In the present paper, yield increases and utilization levels of N, P and K that were obtained when chopped plant material was applied to vegetables in a stockless organic farming system are presented. The sustainability of the method is discussed with respect to the redistribution of nutrients within the farm.

MATERIALS AND METHODS

Overview of the experiments

Vegetables (red beet and white cabbage, see below) were grown in four seasons (1998–2001) to study the effects of mulching on yield levels, nutrient balance and soil nutrient availability. Each year, the effect on yields was studied of one, and in some cases two, applications of a 3 cm cover of chopped plant material. The treatments were integrated within trials that also included various green manure and living mulch treatments, as described by Riley & Brandsæter (2001) and Riley & Dragland (2002). Only the chopped plant mulch results are presented here. Residual effects of mulching on subsequent spring barley crops (*Hordeum vulgare* L., cv. Thule) were measured in 1999–2002. The experimental plots were each year located in different parts of one field with relatively homogenous soil conditions. Yield levels and contents of N, P and K in saleable products, crop residues and mulch material, were recorded each year. Residual levels of mineral

N in the soil were measured each year after harvest. Soil concentrations of P and K were measured preliminarily in 1998, and in more detail in 1999. Weeds were controlled manually in the experiments, and thus weed presence did not markedly affect the yield data presented here.

Location and climatic conditions

The experiments were perfomed at Apelsvoll Research Centre division Kise (60º46'N, 10º49'E), on the western bank of Lake Mjøsa. The growing season at Kise is May–September, with warm, relatively dry summers. Selected weather data for the experimental years are shown in Table 1, together with long-term mean values. Rainfall sums and temperatures were close to long-term mean values, but in all years there was less sunshine than normal, and consequently lower evaporation sums. In June 1999, there was high rainfall shortly after mulch application (precipitation 131 mm, compared with 59 mm normally), which may have caused leaching of nutrients. In June–July 2000 the weather was colder and wetter than normal (mean temperature 13.5ºC and precipitation 162 mm, compared with normal values of 14.4ºC and 125 mm). This probably caused both leaching and delayed growth in that year. The trials were irrigated whenever moisture deficits exceeded 30 mm.

Soil physical conditions

The soil was developed on a morainic till, with 25–30 cm loamy topsoil overlying a highly compact, silty sand subsoil. The soil contains gravel and frequent stones and boulders. It is classified as an imperfectly drained brown earth (gleyed melanic brunisol according to Canada Soil Survey, eutric cambisol according to USDA Soil Survey). Mean data from 16 profiles distributed over the experimental field are presented in Table 2. The ignition loss data, corrected for

TABLE I

Weather conditions in the growing season (May–Sept.) of the trial years, relative to long-term values, 1961–1990.

	Rainfall (mm)	Air temperature (ºC)	Sunshine (h)	Evaporation (mm)
1998	308	11.7	846	262
1999	339	13.0	1002	295
2000	307	12.3	913	293
2001	284	12.8	894	290
Long-term mean values	309	12.2	1046	335

TABLE 2

Physical properties of the soil, mean data from 16 soil profiles within or adjacent to the experimental site.

	Depth (cm)				
	0–15	15–30	30–45	45–60	60–75
Gravel[1]	15	16	23	17	21
Sand[2]	53	54	71	61	65
Silt[2]	29	28	21	31	28
Clay[2]	18	18	8	9	7
Ignition-loss[3]	8.1	7.8	2.6	2.0	1.8
Dry bulk density[4]	1.45	1.45	1.72	1.84	1.91
Total porosity	46.4	47.1	36.7	33.0	30.5
Available water[5]	23.2	21.9	13.0	13.8	14.4
Wilting point[6]	12.5	12.3	6.7	7.4	5.7
Air capacity[7]	10.7	12.9	17.0	11.8	10.4
Permeability[8]	11.8	11.6	25.6	14.3	5.2

[1]Weight % > 2 mm of bulk soil.
[2]Weight % < 2 mm, after USDA classification.
[3]Weight % < 2 mm, ignition loss at 550ºC.
[4]Measured in undisturbed cores, Mg m^{-3}.
[5]Moisture at –10 to –1500 kPa tension, % v/v
[6]Moisture held at –1500 kPa tension, % v/v
[7]Air-filled porosity at –10 kPa tension, %.
[8]Air permeability at –10 kPa tension, μm^2.

clay content as proposed by Riley (1996), indicate organic matter contents of approximately 5% in topsoil and 1% in subsoil. The topsoil has a relatively high storage capacity for plant-available water, whilst that of the subsoil is low. The soil is well aerated, but the high permeability of the subsoil (5–10 cm h^{-1}) suggests that leaching may be rapid.

Soil chemical conditions

The initial soil P and K status of the experimental field is shown in Table 3. The topsoil (0–25 cm) and subsoil (25–60 cm) of 12 blocks was sampled in May 1998 (six each for the 1998 and 1999 trials), and the topsoil of nine blocks (used in the 2000 trial) in May 2000. On each occasion, six to eight auger samples per block were bulked. As the values obtained in 1998–2000 were comparable, it was assumed that they were also representative for the part of the field that was used in the 2001 trial.

Soil pH was measured in a soil-water suspension (1:2.5 v/v). Extractable nutrients (P, K, Ca, Mg) were determined by the method of Égner *et al.* (1960), where the soil is extracted with an AL-solution (0.1 M ammonium lactate and 0.4 M acetic acid, pH 3.75) with a ratio of soil to solution of 1:20 (w/v). Potassium was also extracted by boiling the soil sample for 10 min in 1 M nitric acid (K-HNO_3), as described by Pratt (1965). Values of AL-extractablc P and K are used in Norway for determining fertilizer applications. The K-HNO_3 minus the K-AL

TABLE 3

AL-extractable P and K and nitric acid extractable K of the topsoil (0–25 cm). Means of six plots per trial of the 1998 and 1999 trials, sampled in May 1998, and of nine plots in the 2000 trial, sampled in May 2000.

	Plots used in 1998 trial			Plots used in 1999 trial			Plots used in 2000		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
P-AL (mg kg^{-1})	30	23	34	37	31	44	28	25	33
K-AL (mg kg^{-1})	61	49	82	82	71	91	63	51	71
K-$HN0_3$ (mg kg^{-1})	280	240	310	310	280	340	no data	–	–

value, hereafter called acid-soluble K, is used to estimate the K reserves that may become available to plants over time. P-AL values < 25, K-AL values < 65 and K-HNO_3 values < 300 mg K kg^{-1} dry soil are classified as low, whilst P-AL values > 65, K-AL values > 155 and K-HNO_3 values of > 800 mg K kg^{-1} dry soil are classified as high. On average, the topsoil contents of AL-extractable P and K in the experimental field were medium to low, and the content of K-HNO_3 was low (Table 3). The subsoil values for P-AL and K-AL were generally even lower, varying from 12 to 42 for P-AL (average 25) and from 26 to 57 (average 37) for K-AL, respectively. The subsoil K-HNO_3 values varied from 184 to 266 mg K kg^{-1} (average 217).

The topsoil pH values were quite even, as they varied from 5.8–6.2. In the subsoil, they varied somewhat more, from 6.1 to 6.8. Both topsoil and subsoil concentrations of AL-extractable magnesium and calcium were high or very high.

Cropping history

The field was used for fertilizer and irrigation trials in cereals and potatoes from 1976 to 1986, followed by a soil tillage experiment with the same crops from 1987 to 1995. The field was converted to organic farming in 1996–1997, by incorporating a green manure crop in Autumn 1996, followed in 1997 by growing barley undersown with a mixture of red clover (*Trifolium pratensis* L. cv. Bjursele), timothy grass (*Phleum pratensis* L. cv. Grindstad) and meadow fescue (*Festuca pratensis* Huds. cv. Fure). The undersown crops grew throughout the autumn. In the spring of 1998, one part of the field was cultivated and used for the initial trial, whilst another part was used to provide mulch material from the ley undersown the previous year. Later trials were established after cropping with barley for one year previously. Mulch material was obtained from pure red clover stands located on, or close to, the trial field in 1999–2000, and from a neighbouring farm cocksfoot ley (*Dactylis glomerata* L.) in 2001.

Test crops and mulch material

To provide one crop with a moderate and one with a high nutrient demand, red beet (*Beta vulgaris* L. cv. Action) and Dutch white cabbage (*Brassica oleracea* L. *var. capitum* cv. Eton) were used as test crops. Plants were sown in plugs under glass and planted out in late May. Row spacing was 75 cm and plant spacing was 20 cm in red beet and 40 cm in cabbage. The vegetables were grown on 1.5 × 18–20 m^2 beds that contained two rows of plants, with 9–10 m for each crop. The number of replicates of the treatments comparing mulch applications was six in

1998, six (or nine in some cases) in 1999–2000 and four in 2001. Mulch material was partially incorporated by inter-row rotovation on three replicates in 1998. The high replicate number in 1999 and 2000 was achieved by combining mulching as split plots with green manure treatments, as described by Riley & Dragland (2002). The latter treatments showed no interaction with the mulch effects reported here.

The mulch treatments tested each year were modified, according to experience gained in the previous year. In 1998, a mixed sward of red clover (80%) and timothy grass (20%) was used, in 1999 and 2000 pure red clover, and in 2001 a pure cocksfoot sward. The clover material was harvested each year before flowering whilst the cocksfoot used in 2001 was harvested at early heading. In the first year, a large amount of mulch material (90–100 Mg FW ha^{-1}) was applied either once, 2 weeks after planting on 28 May, or twice, 2 and 5 weeks after planting. In the second year, a similar amount was applied either 3 weeks or 6 weeks after planting on 26 May, or on both occasions. The whole surface between rows and between plants was covered with mulch in both years. In the third year, smaller amounts of mulch were compared with the amount used in previous years for one mulch application. Amounts of 30, 60 and 90 Mg FW ha^{-1} were given in single applications 4 weeks after planting on 24 May. The smallest mulch application was made within plant rows, allowing mechanical weeding between them, whilst the medium and high applications were spread over the whole surface. At the medium level, the effect of incorporation by inter-row rotovation was compared with leaving the mulch on the surface. In the final year, red clover material was not available, due to harsh winter conditions. Instead, a single application of 45 Mg FW ha^{-1} of conventionally fertilized cocksfoot was made, covering the whole surface, 3 weeks after planting on 22 May. The dry matter (DM) content of this material was twice as high as that of clover, so in terms of dry matter the application was roughly comparable to the previous applications of clover.

Plant sampling and analysis

The yield of the material used for mulching was measured on 3 × 1 m^2 plots at each time of application in 1998–2000, and DM content and concentrations of N, P and K were recorded. In 1999 the amount of clover mulch remaining was measured 3 weeks after application in six 80 cm^2 metal cylinders. These were pushed into the mulch material, and any detectable soil was removed by hand. In 2001 the amount of cocksfoot mulch remaining was measured after the red beet harvest, using eight 1200 cm^2 metal frames. The amounts of DM as well as N, P and K concentrations were measured in both cases.

Red beet was harvested earlier than white cabbage. Harvest dates for red beet varied between 17 August and 15 September, whilst those for cabbage varied between 18 September and 6 October. At harvest, the weights of saleable products and crop residues were recorded and samples of both were taken for analysis of DM content and concentrations of N, P and K. Harvest plot size was 12–14 m^2. Only the saleable products were removed from the field. Leaves and stems were incorporated into the soil by rotovating soon after harvest, except in 2000, when wet weather prevented this. The plots were ploughed in the following spring.

Total N and P concentrations were measured by colour photometry using a Skalar autoanalyser, and K concentrations by standard flame photometry, after digestion in sulphuric acid/hydrogen peroxide in the presence of Se and $LiSO_4$ catalysts. This procedure is a modified Kjeldahl technique (Allen *et al.,* 1975).

Soil mineral N

Within about one week after harvest of each crop, the soil was sampled to analyse the amount of mineral N (NO_3^- and NH_4^+) that remained in the soil profile (0–60 cm). Samples were frozen, ground without thawing and extracted by shaking with 1 M KCl. Concentrations of NO_3^--N and NH_4^+-N were determined by photometric methods using an Aquatec Autoanalyser, and corrected for soil moisture content. Results are expressed on an area basis, assuming average bulk densities and after correcting for the average gravel content of 15% (Table 2).

Studies of soil nutrient concentrations in 1998 and 1999

In 1998, topsoil samples were taken during the growing season for analysis of P-AL, K-AL and K-HNO_3 on the treatments with no, one or two mulch applications without incorporation (three replicates). However, no statistically significant differences in soil P and K concentrations between the treatments were obtained. Hence the results are not shown. In 1999, soil P and K concentrations were recorded only on blocks without green manure in the treatments without mulch and with two mulch applications (six replicates). This increase in the number of replicates improved the reliability of the results. The topsoil was sampled (four or five auger samples per plot) by hand during the growing season and by machine in spring and after harvest. Subsoil sampling by hand during the season was not possible, due to the soil's high content of gravel and stones. The amounts of P and K in topsoil were calculated as for soil mineral N.

Apparent recoveries of nutrients

The efficiency of nutrient use from chopped plant mulch was assessed by apparent recovery of nutrients. That is the amount of N, P or K in above-ground plant material in treatments receiving no mulch subtracted from the amounts in treatments receiving mulch, expressed as percentages of the amounts applied. This way of calculating nutrient efficiency may overestimate the amount of nutrients originating from the mulch if the mulched crops in fact take up more nutrients directly from soil, due to deeper rooting, than do the control crops. However, not subtracting the nutrients taken up in the control treatment would imply that all nutrients in crops originated from the chopped plant mulch, which is obviously not the case.

Statistical analysis

All data were analysed by suitable ANOVA models, in which mulch treatments were considered at a split-plot level when appropriate, using statistical packages (either MSTAT, Nissen & Mosleth, 1985, or SAS, SAS Institute Inc., 1989).

RESULTS AND DISCUSSION

Nutrient content and growing area requirement of green mulch

The nutrient concentrations, botanical composition of the plants used for mulch, as well as the area required to produce the required mulch material at each application date are shown in Table 4. N concentrations were mostly high, but P and K concentrations varied considerably between years. For red clover (mixed with timothy in 1998), the concentrations indicate a sub-optimal supply of both P and K in 1998, and of P in 2000. As the field P-AL levels were generally medium to low, a low concentration of P in the plant material was to be expected. On average, the material may be compared to solid cattle manure with respect to N and K concentration on a DM basis, whereas the P concentration was somewhat lower. The total amounts of N, P and K, respectively, applied by two applications of clover mulch, were 587, 53 and 287 kg ha^{-1} in 1998 and 470, 71 and 490 kg ha^{-1} in 1999. The single early application in these two years provided slightly more than half these quantities, whilst in 2000 the single, slightly later application of a comparable FW amount contained 379, 29 and 331 kg ha^{-1}. The single application of cocksfoot mulch in 2001 contained 270, 55 and 290 kg ha^{-1} of N, P and K.

The area required for producing a clover mulch cover of approximately 90 Mg FW (or 12 Mg DM) ha^{-1} was measured in 1998–2000. Linear regression (n = 6) showed that, on a certain date, the yield of DM equalled 680 kg ha^{-1} + 87* days from 1 May (r^2 = 0.85). Hence, for an application of 90 Mg ha^{-1} in mid-June, a clover area of 2.2 to 2.9 ha was required per ha of vegetables (Table 4). For a later application, the required area decreased to ca 1.5 ha. The N uptake in the clover

TABLE 4

Yields, botanical composition, dry matter and total N, P and K concentrations of mulch material and the mulch growing area required for each application in 1998 and 1999. For 2000, the area requirement is shown for the three application levels used, 30, 60 and 90 Mg FW ha^{-1}.

Date	Yield level (Mg FW ha^{-1})	Botanical composition	DM %	N	P % DM	K	Area factor (ha ha^{-1})
11 June 1998	32.2	75% red clover[1]	14.5	2.48	0.22	1.14	2.9
2 July 1998	57.3	”	11.8	2.19	0.20	1.15	1.7
17 June 1999	42.3	100% red clover	9.6	2.95	0.39	2.83	2.2
7 July 1999	71.0	”	10.5	2.13	0.37	2.45	1.3
21 June 2000	39.6	100% red clover	16.0	2.64	0.20	2.30	0.8/1.5/2.3
15 June 2001	—	100% cocksfoot[2]	27.4	2.19	0.45	2.35	no data

[1]Mixed sward with 25% timothy grass used in 1998. [2]Only 45 Mg FW ha^{-1} was used due to high DM%.

was also described by a regression equation: kg N ha^{-1} = 49 + 0.16*kg DM ha^{-1} (r^2 = 0.87). The equations may be used to decide vegetable planting dates.

Breakdown rate of mulch material

Three weeks after the first mulch application in 1999, only 15% of the original 890 g DM m^{-2} of clover mulch material was left on the surface. The N, P and K concentrations in this material were 3.10, 0.52 and 1.03%, respectively. Hence, the N and P concentrations had increased in the DM, whereas that of K had been diluted. The remaining mulch contained only 15% of the original N, 20% of the P and 5% of the K. By contrast, almost 90% of the DM of the cocksfoot material used in 2001 remained on the surface after two months. The N, P and K concentrations in this material were 2.04, 0.40 and 0.69%, respectively, suggesting that only about 20% of the N and P, but 75% of the K, had been released.

The reason for these widely different patterns of decomposition was probably related to the lignin content of the plants. The proportion of stems, and thus the lignin content, was larger in cocksfoot than in red clover. Red clover regrowth after one late mowing in July 2001 was harvested in mid-October and air-dried. Analysis showed that 44% of the average 0.36% P in DM was water-soluble, all of which was inorganic. The inorganic P fraction in leaves is known to increase on drying (Sharpley & Reed, 1982), so that analysis of air-dried material may not reflect the fraction of inorganic P in fresh plant material. However, desiccation of the mulch material will often occur in the field, and hence it is assumed that the values obtained represent the inorganic and water-soluble P fraction of the chopped mulch reasonably well. The results suggest that much of the P in chopped plant mulch is probably readily available to microorganisms. As also the N concentration in the clover material was sufficiently high for rapid decomposition, the almost complete breakdown of clover mulch during one month after application in 1999 was to be expected.

Yields of vegetables and crop residues

In most cases, mulching increased both vegetable yields and crop residues, but there were variations between years, between crops and between treatments (Table 5). In the first year, chopped clover/grass mulch gave small, non-significant yield increases in red beet and larger, significant increases in white cabbage. The effect of mulch incorporation was not significant, and data shown in Table 5 are, therefore, means of treatments with and without incorporation. The low response of red beet to mulching may have been due to nutrient leaching below this crop's rooting depth, due to high rainfall in June of that year.

TABLE 5

FW yields of saleable products and above ground crop residues of red beet and white cabbage in 1998–2001, as affected by number of mulch applications, mulch fresh weight quantity (large = 90–100 Mg ha^{-1}, medium = 60 Mg ha^{-1}, small = 30 Mg ha^{-1}) and timing of mulching (weeks after planting). Mulch treatment effects are shown as increments relative to the treatment that received no mulch material.

Number of mulchings	Mulch FW quantity	Application time (weeks)	FW yield (Mg FW ha^{-1})			
			Red beet		White cabbage	
			Products	Residues	Products	Residues
1998 trial	(Clover/grass)					
0	None	–	38.9	10.2	40.6	34.8
1	Large	2	+ 0.1	+ 0.9	+ 6.0	+ 6.7
2	Large	2 + 5	+ 4.6	+ 2.2	+ 12.9	+ 10.1
		$LSD_{5\%}$[1]	(7.2) ns	(2.1) ns	9.4*	4.2***
1999 trial	(Clover only)					
0	None	–	22.0	5.8	52.0	33.7
1	Large	3	+ 11.3	+ 2.0	+ 19.6	+ 9.5
1	Large	6	+ 2.8	+ 1.5	+ 11.3	+ 5.8
2	Large[2]	3 + 6	+ 13.6	+ 4.8	+ 24.9	+ 10.6
		$LSD_{5\%}$	1.6/2.0***	0.4/0.6***	3.8/6.4***	1.7/2.9***
2000 trial	(Clover only)					
0	None	–	15.7	4.5	34.0	22.8
1	Small	4	+ 0.6	+ 0.9	+ 1.5	+ 1.9
1	Medium	4 (on surface)	+ 3.0	+ 1.6	+ 7.0	+ 4.1
1	Medium	4 (rotovated)	+ 6.1	+ 2.6	+ 5.2	+ 4.0
1	Large	4	+ 6.7	+ 3.2	+ 9.1	+ 6.1
		$LSD_{5\%}$	1.6***	0.5***	4.7***	3.0***
2001 trial	(Grass only)					
0	None	–	31.3	6.7	51.6	30.8
1	Large[3]	3	+ 11.1	+ 4.9	+12.5	+ 10.7
		$LSD_{5\%}$	3.5**	2.0**	8.0**	3.9**

[1]*** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$, + = $p < 0.1$, ns = not significant.
[2]Six replicates used for two mulch applications, and nine for other treatments (LSD nine replicates/LSD six replicates).
[3]Only 45 Mg FW ha^{-1} of cocksfoot used, but similar DM amount as for clover.

In the second year there were large, significant yield increases in both crops with the use of clover mulch. A single, early application was considerably more effective than a single, late application, particularly in red beet. Two applications gave only a slightly higher yield than one application in beet, but somewhat more in cabbage.

In the third trial year, when small, medium and large clover mulch applications were compared, there was little yield response with the smallest amount used (30 Mg ha^{-1}). A medium amount (60 Mg ha^{-1}) gave somewhat greater responses. In red beet the response was best when the mulch was incorporated into the soil by inter-row rotovation, probably because this gave more efficient utilization of N. This was not the case, however, in cabbage, where leaving the mulch on the surface was best. This may have been because, with incorporation, some white clover plants re-established themselves on blocks that had been undersown with this crop the previous year, causing competition with the cabbage late in the growing season. Alternatively, some damage to cabbage roots may have been caused by the inter-row rotovation. The generally low yield level in this year was probably due to leaching after very cool, wet weather in June and July. A single, large mulch application nevertheless gave comparable percentage yield increases as in previous years.

In the final year, when a large application of pure cocksfoot grass mulch was made, the yield increases were large and highly significant in both crops. As this mulch material remained on the surface without noticeably decaying for much longer than the clover material, it clearly had more potential for controlling weeds. However, as weeds were controlled manually, the effect was most likely a result of nutrient supply.

The overall FW increase in red beet with a single large mulch application, averaged over four years, was 8.9 Mg ha^{-1} (+26%), whilst the corresponding figure for two applications, averaged over two years, was 12.6 Mg FW ha^{-1} (+33%). In white cabbage, the corresponding overall FW increases were 19.5 Mg ha^{-1} (+26%) and 29.2 Mg FW ha^{-1} (+36%). Plant DM concentrations were often somewhat reduced by the use of mulch, usually by about 1–2% in both products and residues (data not presented). This probably indicated better vegetable eating quality, but slightly reduced the percentage yield increase when viewed in terms of dry matter rather than fresh weight. Nevertheless, the yield responses were substantial even on this basis.

Crop nutrient uptakes and apparent recovery of applied nutrients

The use of mulch gave consistently large and statistically significant increases in the concentrations of N and K in both vegetable products and in crop residues (data not shown). There were increases in P concentrations also, but these were not always significant. Crop nutrient uptakes were thus in all cases considerably

TABLE 6

Total nutrient uptakes in above-ground parts of red beet and white cabbage in 1998–2001, as affected by number of mulchings, mulch fresh weight quantity (large = 90–100 Mg ha^{-1}, medium = 60 Mg ha^{-1}, small = 30 Mg ha^{-1}) and timing of mulch application (weeks after planting). Mulch treatment effects are shown as increments relative to the treatment that received no mulch material.

Number of mulchings	Mulch FW quantity	Application time (weeks)	Nutrient uptake (kg ha^{-1})					
			Red beet			White cabbage		
			N	P	K	N	P	K
1998 trial	(Clover/grass)							
0	None	–	110	14.6	115	126	24.7	181
1	Large	2	+ 5	– 0.1	+ 4	+ 40	+ 4.5	+ 27
2	Large	2 + 5	+ 23	+ 1.7	+ 249	+ 78	+ 9.4	+ 58
		LSD$_{5\%}$[1]	(22)+	(2.3) ns	(23)+	33**	4.5**	23***
1999 trial	(Clover only)							
0	None	–	58	8.1	129	134	28.4	215
1	Large	3	+ 37	+ 2.5	+ 84	+ 71	+10.3	+ 80
1	Large	6	+ 14	+ 1.1	+ 27	+ 45	+ 5.1	+ 47
2	Large[2]	3 + 6	+ 54	+ 4.0	+ 125	+ 104	+ 12.2	+ 110
		LSD$_{5\%}$	5/8***	1.1/1.5***	9/11***	10/15***	2.0/2.4***	13/20***
2000 trial	(Clover only)							
0	None	–	39	4.5	67	102	13.7	139
1	Small	4	+ 2	+ 0.1	+ 5	+ 10	+ 1.3	+ 7
1	Medium	4 (on surface)	+ 9	+ 0.6	+ 6	+ 31	+ 2.8	+ 21
1	Medium	4 (rotovated)	+ 20	+ 1.3	+ 28	+ 28	+ 2.1	+ 13
1	Large	4	+ 24	+ 2.3	+ 38	+ 53	+ 4.9	+ 34
		LSD$_{5\%}$	4***	0.4***	5***	15***	1.9***	18***
2001 trial	(Grass only)							
0	None	–	80	26.4	130	8.1	30.3	171
1	Large[3]	3	+ 33	+ 13.5	+ 78	+ 29	+ 11.6	+ 48
		LSD$_{5\%}$	24*	8.5**	24***	15**	7.2**	33*

Footnotes as in Table 5.

greater with the use of mulch than without, except for those of P in red beet in 1998 (Table 6). The data shown are total uptakes in products and above-ground residues. High uptakes in red beet in 1998 were a result of somewhat later harvesting of this crop that year. The amounts removed from the field in crop products varied somewhat between years, particularly in the case of white cabbage, but they varied very little between treatments within years. Hence, the climatic conditions in each growing season influenced the nutrient uptake more than the amount of mulch applied. In red beet, the proportions removed corresponded to 64–75% of the total N uptake, 77–85% of the P and 58–68% of the K. The corresponding figures for white cabbage were 52–84% of N, 55–90% of P and 49–84% of the K.

The apparent percentage recoveries of the nutrients supplied in the mulch material were higher in cabbage than in red beet, and were normally highest for K and lowest for P (Table 7). They varied considerably between years, being lowest in 2000, when much of the total rainfall in that growing season came shortly after mulch application. The apparent recoveries appear low in the case of clover mulch, considering the rapid decomposition of this material. Only in cabbage in 1999 did the recoveries account for an appreciable proportion of the nutrients released from the clover mulch material. The recoveries from cocksfoot mulch material in 2001, on the other hand, were comparatively high, in view of the fact that much of the material remained on the soil surface throughout the growing season.

With respect to N, a high nutrient efficiency is difficult to achieve due to volatilization and other losses. With respect to P, the low recoveries reflect that the amount of mulch used was determined by N demand, and more P was applied than the crops were able to take up. For K, the high recoveries in 1999, especially in red beet, demonstrate that luxury nutrient uptake, due to excess availability, may affect the apparent recovery.

Mineral N in soil after harvest

An increased level of soil mineral N in 0–60 cm depth was normally found after harvest following the application of mulch (Table 8), particularly in the case of red beet. This crop was harvested earlier than cabbage, and had less time for N uptake. Two applications clearly gave a larger residue of mineral N in soil than did one application. Comparable amounts of soil mineral N (57 kg ha^{-1} with two clover mulch applications and 15 kg ha^{-1} without chopped clover mulch) were found in a Finnish study with white cabbage (Jaakkola, 1995).

In relation to the amounts of N applied, the residues of soil mineral N were nevertheless small, in no case more than 10% of the N applied. Some N may have been leached to below 60 cm, especially in the wet season of 2000, when levels of soil mineral N were generally low. However, ammonia volatilization was

TABLE 7

Nutrient use efficiency in above-ground parts of red beet and white cabbage of N, P and K applied in mulch material, after subtraction of uptakes measured without mulching.

Number of mulchings	Mulch FW quantity	Application time (weeks)	Nutrient uptake (apparent % recovery)					
			Red beet			White cabbage		
			N	P	K	N	P	K
1998 trial	(Clover/grass)							
1	Large	2	2	0	3	12	15	18
2	Large	2 + 5	4	3	8	13	18	20
1999 trial	(Clover only)							
1	Large	3	14	7	33	27	30	32
1	Large	6	7	3	11	22	14	20
2	Large	3 + 6	12	6	46	22	17	38
2000 trial	(Clover only)							
1	Small	4	2	1	5	8	13	6
1	Medium	4 (on surface)	4	3	3	12	15	10
1	Medium	4 (rotovated)	8	7	13	11	11	6
1	Large	4	6	8	9	14	17	10
2001 trial	(Grass only)							
1	Large	3	12	25	27	11	21	17

TABLE 8

Soil mineral nitrogen measured in the soil profile (0–60 cm) shortly after harvesting red beet and white cabbage, as affected by the use of mulch material in 1998–2001, and percentages of the amounts of nitrogen applied in mulch. Mulch treatment effects are shown as increments relative to the treatment that received no mulch material.

Number of mulchings	Mulch FW quantity	Application time (weeks)	Red beet		White cabbage	
			N-min (kg ha^{-1})	% of applied	N-min (kg ha^{-1})	% of applied
1998 trial	(clover/grass)	–				
0	None	–	44	–	18	–
1	Large	2	+ 29	9	+ 5	2
2	Large	2 + 5	+ 54	5	+ 3	<1
		$LSD_{5\%}$[1]	24**		(6) ns	
1999 trial	(clover only)					
0	None	–	32	–	11	–
1	Large	3	+ 26	10	+ 4	1
1	Large	6	+ 15	9	+ 4	2
2	Large[2]	3 + 6	+ 45	10	+ 14	3
		$LSD_{5\%}$	13/18***		2/6***	
2000 trial	(clover only)					
0	None	–	14	–	15	–
1	Small	4	+ 3	3	+<1	<1
1	Medium	4 (on surface)	+ 4	2	+1	<1
1	Medium	4 (rotovated)	+ 6	3	+ 3	1
1	Large	4	+ 11	3	+ 6	2
		$LSD_{5\%}$	5**		3**	
2001 trial	(grass only)					
0	None	–	22	–		
1	Large[3]	3	+ 9	4	nd	–
		$LSD_{5\%}$	5**			

Footnotes as in Table 5.

probably the main reason for the large N losses, in accordance with the laboratory study of Janzen & McGinn (1991) and the field study of Larsson *et al.* (1998). In the laboratory, up to 14%, and in the field, 17–39% of the N applied in mulch from various plant species was lost as ammonia.

The residues of mineral N found in the soil in autumn are, under Norwegian conditions, to a large extent leached before crops can make use of them in the following year. Better use of residual N after vegetables has nevertheless been found in barley than in potatoes (Riley, 2002), which suggests that some of the N may be utilized in the following year by crops with rapid development of a finely branched root system.

Fate of P and K applied as mulch in 1999

In 1999, the nutrient surplus of P (applied in mulch minus uptake in saleable products removed from the field) supplied by two mulch applications was 61 and 44 kg ha^{-1} in red beet and white cabbage, respectively, whereas the corresponding surplus of K was 322 and 292 kg ha^{-1}. These large surpluses, as well as the low apparent recoveries discussed above, were reflected in significant increases in soil P-AL, K-AL and acid-soluble K concentrations from spring to autumn (Table 9). It should be noted that no significant differences between treatments and crops were found in the initial spring values of soil P and K.

In the subsoil, no changes in P or K concentrations were found during the season. As the subsoil layer measured here was rather thick (25–60 cm), the P-AL values varied more at this depth than in the topsoil, and because the surplus of P

TABLE 9

Concentrations of AL-extractable P and K, and acid-soluble K of the topsoil (0–25 cm) measured on 20 May and 21 October 1999, before and after cultivation of red beet and white cabbage, on treatments with either no mulch or two mulches. Changes from spring to autumn are shown as increments.

	Red beet		White cabbage	
	No mulch	Two mulches	No mulch	Two mulches
P-AL (mg kg^{-1})				
20 May	28	27	25	25
21 October	0	+8*	–1	+4*
K-AL (mg kg^{-1})				
20 May	67	71	62	65
21 October	–3	+57**	–11	+48**
ACID-SOLUBLE K (mg kg^{-1})				
20 May	235	232	219	232
21 October	–8	+69*	–13	+44**

was low compared with that of K, possible increases in subsoil P concentrations may have been obscured. The unchanged subsoil K values suggest that there was probably no transport of this nutrient from topsoil. The increase in topsoil P-AL values from 20 May to 21 October amounted to 25 and 15 kg P ha^{-1} in red beet and white cabbage, respectively. This means that approximately 36 and 29 kg P ha^{-1} of the surplus from cultivation of these crops, respectively, was not adsorbed as P-AL in the soil. With the larger surplus, found after red beet, the fraction of P accounted for as soil P-AL was slightly larger, 41% compared with 34% after cabbage. Without mulch application, there was no change in the topsoil P-AL value. Hence, the P taken up in saleable products in this treatment, 8 kg P ha^{-1} in red beet and 19 kg in cabbage, had been replenished.

If it is assumed that the same amounts of P were also supplied from the soil in the treatment with mulch application, the amount of surplus P that was not absorbed as P-AL in the mulch treatment increases to 44 kg P ha^{-1} for red beet and 48 kg for cabbage. This surplus P may have been bound in soil faunal biomass, and hence was not extracted by AL, or it may have been adsorbed to soil minerals in a form not extractable by AL-solution. To increase the Bray 1-extractable P concentration (comparable to P-AL) by 1 mg kg^{-1} soil in a topsoil layer of 15 cm depth, 17 kg ha^{-1} P surplus was required (Barber, 1979), in a soil where the initial Bray 1-P value was 18 mg kg^{-1} soil. In the present study, the surplus required to increase the P-AL concentration by 1 mg kg^{-1} in the 25 cm topsoil layer with a comparable initial P-AL concentration, was 7.6 kg for red beet and 11 for cabbage. Corrected for the difference in soil depth, the value in the present study becomes 5–6 kg P ha^{-1}, which is considerably lower than the results found by Barber for conventional P fertilizer. This indication may confirm that P applied as chopped plant mulch remains less strongly adsorbed in soil than does P applied in mineral fertilizer, as previously shown by Dalton *et al.* (1952) and Fuller *et al.* (1956).

The value of 5 kg P ha^{-1} corresponds well with values found by Øgaard (1995) in a Norwegian long-term experiment with mineral P-fertilizer in a soil with an initial P-AL value of 50 mg P kg^{-1}. In the latter, a surplus of 6.5 kg P ha^{-1} increased the P-AL concentration by 1 mg kg^{-1} in the 0–20 cm soil layer. In a 25 cm layer, the amount of P surplus required to increase P-AL by 1 mg would have been approximately 8 kg, which is far below the value found by Barber, but again higher than in the present study. The clay content of the soil is related to the required P surplus to increase P-AL or Bray 1-P. The amount of clay was 18% in the present study, 25% in the study of Øgaard (1995) and 28% in the study of Barber (1979). Hence, the somewhat higher content of clay in the other two studies may explain some of the larger effect of P surplus in the present study.

To assess the sorption capacity of the soil used in the present study, aliquots of soil that had not received mulch were shaken for 24 h with 0.01 M $CaCl_2$ solution containing 0–30 mg P 1^{-1} as phosphate ions, and the amount of P that remained in solution was measured. The average sorption maximum (S_{max}) for four soil samples was 425 mg P kg^{-1} air-dry soil (range 345–555). This is comparable to S_{max} values found for the soils presented by Bakkegaard (1999), where S_{max} was 457 mg P kg^{-1} after 30 years of cereal production with no P-fertilizer and a P deficit of 17 kg ha^{-1} y^{-1}. This shows that the soil in the present study had the ability to adsorb as much P as a soil that had been depleted of P over a period of 30 years.

The changes in topsoil concentrations of K-AL and acid-soluble K during the growing season differed somewhat between red beet and cabbage (Figure 1). For red beet, the largest increment in both K-AL and acid-soluble K values due to mulching was achieved between harvest and the final soil sampling. In cabbage, however, a large increment occurred after the first mulch application. Thereafter, the levels of both K-AL and acid-soluble K were significantly higher in the mulch treatment than in the control. These differences between crops are difficult to explain.

The increases in topsoil K-AL values corresponded to 209 and 174 kg K ha^{-1} in red beet and cabbage, respectively, whilst the respective increases in acid-soluble K corresponded to 252 and 199 kg K ha^{-1}. Hence, the total increase in extracted soil K (K-AL plus acid-soluble K) was larger than the K surplus for both crops. The amount of K not accounted for amounted to 139 kg K ha^{-1} for red beet and 81 kg K ha^{-1} for cabbage. In the control plots, the K uptake was 90 kg K ha^{-1} for red beet and 135 kg for cabbage. These amounts of K are considerably larger than the decreases in extracted soil K that were found for treatments without mulch, which were 40 and 87 kg K ha^{-1}, respectively, for red beet and cabbage. Hence, the experimental soil had a capacity to replenish some of the K taken up by plants. Such replenishment may also explain why the concentrations of extracted soil K in autumn were above the level expected from the mulch derived K surplus.

Residual effects of mulching on subsequent barley yields

Mulching gave large yield increases in barley grown the year after mulching (Table 10), and the effects were significant in three of the four years. It may be noted that the yield increases, on average 0.59 Mg ha^{-1} with a single large application of clover or grass mulch, were of the same order of magnitude as those reported by Korsaeth *et al.* (2002) for the first season after using clover as a green manure subcrop in organic cereals. Comparable yield levels and increases were also found for barley in a mixed as compared to an arable organic farming system (Eltun *et al.,* 2002), where the fertilization level was three times higher in the mixed system. The present yield increases were also equal to or greater than the residual effects in cases of clover plants incorporated before or early in the growing season of the preceding vegetable crop in the present trials (data not presented).

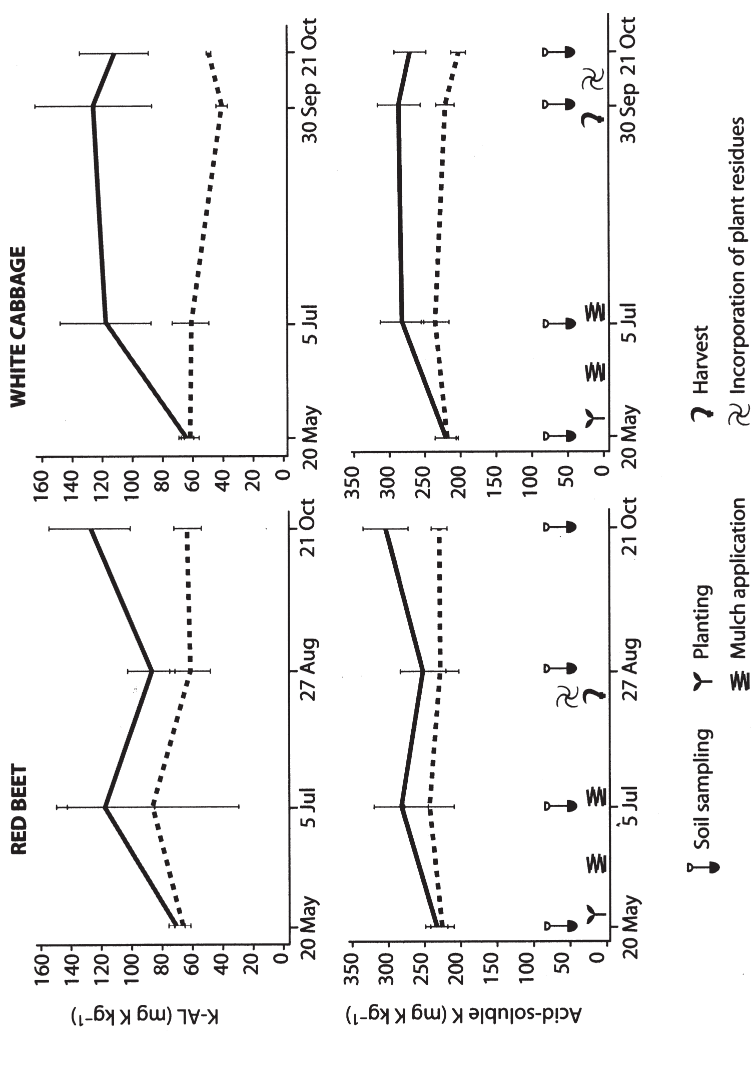

FIGURE 1. Concentrations of plant-available (K-AL) and acid-soluble K in topsoil (0–25 cm) during cultivation of red beet and white cabbage in the growing season of 1999. Two applications of chopped plant mulch (———), no mulch (- - - - -).

TABLE 10

Residual effects of the use of mulch material in 1998-2001 on barley yields, protein concentration and nitrogen uptakes in the following year (1999-2002), and the corresponding percentages that the uptake figures represent in relation to the amounts of nitrogen applied in mulch. Mulch treatment effects are shown as increments relative to the treatment that received no mulch material.

Number of mulchings	Mulch FW quantity	Application time (weeks)	Barley grain		Nitrogen uptake	
			$Mg\ ha^{-1}$	Protein %	$kg\ N\ ha^{-1}$	% of applied
1998 trial	(Clover/grass)					
0	None	–	3.51	9.3	44.2	–
1	Large	2	+ 0.35	– 0.3	+ 3.3	1.0
2	Large	2 + 5	+ 0.44	– 0.1	+ 5.3	0.9
		$LSD_{5\%}$[1]	(0.40) +	(0.3) ns	(5.5) ns	
1999 trial	(Clover only)					
0	None	–	3.04	10.5	43.4	–
1	Large	3	+ 0.98	+ 0.3	+ 15.7	6.0
1	Large	6	+ 0.78	+ 0.3	+ 12.8	6.2
2	Large[2]	3 + 6	+ 1.51	+ 0.5	+ 24.7	5.2
		$LSD_{5\%}$	0.20/0.26***	0.3/(0.6)*/ns	3.2/3.8***	
2000 trial	(Clover only)					
0	None	–	3.49	10.1	48.0	–
1	Medium	4	+ 0.49	+ 0.4	+ 9.0	3.6
I	Large	4	+ 0.38	+ 0.4	+ 7.4	1.9
		$LSD_{5\%}$	0.19***	(0.5) ns	3.7***	
2001 trial	(Grass only)					
0	None	–	1.61	11.5	25.0	–
1	Large[3]	3	+ 0.46	+0.8	+9.8	3.6
		$LSD_{5\%}$	0.34*	0.8*	6.3**	

Footnotes as in Table 5.

There was a general trend towards higher grain protein content after mulching also. Even so, the increased N uptake accounted for only a very small portion (< 6%) of the N applied in the mulch material. It is not possible to distinguish between nitrogen derived from the mineral N reserves found in autumn and that derived from further breakdown of the mulch material or from vegetable residues. Even disregarding the possibility of double counting, a substantial proportion of the applied N remains unaccounted for. As stated above, a large fraction of the applied N was probably lost by ammonia volatilization. In a Swedish study, volatilization losses were found of up to 40% of the N applied in chopped grass mulch, with N concentration comparable to the present case, whilst only about 1% was lost as nitrous oxide (Larsson *et al.,* 1998).

General discussion

Considerable yield increases were found with mulch application, especially for the most nutrient demanding crop, white cabbage. However, the effects varied from year to year. As expected, the variation in yield levels was large when no mulch was applied. This is in accordance with other farming systems comparisons. For example, in a Swiss long-term experiment, FW yields of white cabbage without fertilization varied from 24 to 51 Mg ha^{-1} over three years (Besson *et al.,* 1993), which is comparable to the results in the present study with respect to both yield level and variability. This study attempted to establish whether mulch application would stabilize vegetable yields, compared with the control treatment, but this was not found to be the case. Rather, the yield increase with chopped plant mulch was proportional to the control yield level, so that the effect of mulch was largest in the years when the yield level was generally highest. As the N delivering capacity of the soil is of prime importance in organic vegetable production (Ekbladh, 1995), this result probably means that the N availability from mulch is at least as variable as is the soil N-mineralization. The large variation in apparent recovery, especially that of N, confirms this.

Likely arguments against using chopped plant mulch are that the nutrient recoveries are low, that the N losses have negative effects on the environment and that the system requires a large mulch-growing area. However, by comparison with the use of animal manure, the recoveries reported here may in fact not be unreasonably low. Ekbladh (2000) found that lettuce and leeks took up only 2–12% of the N supplied in composted cattle manure, whereas for poultry manure in the same study, recoveries of up to 100% were found. The difference in recovery may be explained in terms of the widely different concentrations of both total and mineral N in these types of animal manure.

Compared with the N in composted animal manure, N in chopped plant mulch is easily mineralized and volatilized and/or leached. Incorporation of chopped plant mulch into the soil was expected to reduce volatilization, but this amendment gave inconsistent results in the present trials, and in any case incorporation is difficult to accomplish in practice. An alternative to incorporation might be coverage with ammonia absorbing agents. Larsson (1997) found considerable increases in topsoil mineral N a fortnight after the application of chopped grass with > 2% N, especially when the mulch was covered with a 3 cm layer of coniferous wood chips. The increase continued until 70 days after application, after which the soil mineral N decreased again. No crops were grown in this study. However, only 12% of the applied N was leached from the grass, in spite of excess precipitation shortly after mulch application. The leachate from the treatment covered with wooden chips was not measured. These results show that N is rapidly released from mulch, but also that there is a limit to the amount of mineralized N that may be utilized, unless the mulch is covered with substances that absorb ammonia. Janzen & McGinn (1991) prevented volatilization by covering the mulches with a layer of soil. However, this amendment requires extra work and will decrease the weed regulating effect of the mulch. Nevertheless, coverage or other possibilities of decreasing gaseous losses of N should be further studied. The potential losses of large amounts of N_2 fixed by legumes in organic farming systems, which contribute to global climate change, warrant special attention since organic farming aims to be environmentally sound.

Regarding the mulch-growing area, it may in fact be advantageous for stockless organic systems to utilize a small part of the farmland intensively for labour intensive, high-value crops, whereas the largest part is used for perennial green manure crops, requiring little work and seed costs. Even fields that are not suitable for vegetable production, such as former grazing areas for cattle, may be utilized for production of chopped plant mulch. Forage production for sale from grass-clover leys is a poor option for stockless organic systems, as it would cause large deficiencies of P, K and other nutrients. In stockless organic systems, green manure crops are usually cut several times through the season, without removing them from the field. Similar ammonia losses will probably occur from these plant residues as from mulch cover. The residual effect of a previous green manure crop (clover grass) was almost equal when the herbage was removed and when it was left on the field in a Norwegian study (Solberg, 1995), probably because much herbage N was lost as ammonia. Further, the green manure herbage is exposed to losses of P and K by leaching and runoff, especially during freeze-thaw periods. Hence, utilization of chopped plant mulch may be more efficient and sustainable than keeping the herbage on the original green manure field.

Whereas the N recovery of the chopped plant mulch amendment urgently needs improvement, no indications of leaching or other losses were found in the case of P and K, and a considerable amount of the surplus applied in mulch was recovered in the topsoil. Hence, the method seems successful with respect to these nutrients, when care is taken to include all the arable farmland in a crop rotation comprising mulch as well as cash crop production, so as to avoid an uneven distribution of soil mineral nutrients within the farm. If the recovery of N can be increased, this would also lead to better utilization of P and K, as lower amounts could be used, thus giving a better balance with crop requirements.

The imbalance in the area required for mulch production throughout the season imposes a problem. Early in the season, the area required for mulch production is approximately twice as large as later. A farming system with low stock density, where the animals could graze the excess ley regrowth late in the season, may be an efficient way to utilize the plant material produced. As a high proportion of the farm's area is required to produce the amount of mulch necessary for N-demanding crops, a mulch-based system is probably only applicable in the production of valuable vegetable crops or herbs. In such cases, however, the system may be attractive, as vegetable production on all of the farmland would normally be too laborious, and might also involve shorter than optimum crop rotations.

The recovery of nutrients was greatest in the case of mulch material that was broken down slowly (cocksfoot). As the yield levels were generally high the year this kind of mulch was used, it is not possible to assess whether similar amounts of N, P and K applied as cocksfoot and clover mulch would have increased the yield levels differently. This question should be further studied. Longer lasting mulch cover controls weeds more efficiently, and furthermore it reduces soil desiccation as well as stimulating prolonged biological activity close to the soil surface. In organic farming systems, producing mulch material without the potential for biological N fixation seems imprudent. However, mulch from a mixed grass-legume ley, or one obtained by mixing cereal straw and fresh legume material, might be the optimal solution for achieving both adequate nitrogen supply and optimum weed control. The developmental stage of the plants used for mulching also has an impact on the rate of decomposition. Conserving plant material through the winter as hay or silage may provide a possibility for early mulch application, and may even be advantageous with respect to N recovery. All these topics require further study.

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