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Nitrogen Contribution of Various Vegetable Residues to Succeeding Barley and Potato Crops

Stickstoffnachlieferung aus Ernterückständen von Gemüse während nachfolgenden Gerste- und Kartoffelkulturen

Hugh Riley
(Norwegian Crop Research Institute, Apelsvoll Research Centre, Norway)

Summary

Two 2-year field trials were carried out on loam soil, in order to measure the residual effect of four commonly-grown vegetable crops (cauliflower, *Brassica oleracea* L. var. *botrytis;* swede, *Brassica oleracea* L. var. *rapifera;* bulb onion, *Allium cepa* L.; peas, *Pisum sativum* L. var. *medullare*) compared with oats (*Avena sativa* L.). Residual effects of the vegetable crops were assessed in both spring barley and potatoes grown the following year at four levels of N-fertilizer (0, 40, 80 and 120 kg N ha^{-1}).

The amount of total nitrogen found in crop residues was greatest in cauliflower (111 kg ha^{-1}), and was for the other crops, in descending order, 86 kg ha^{-1} in swedes, 54 kg ha^{-1} in vining peas, 42 kg ha^{-1} in mature peas and 21 kg ha^{-1} in onions. The amounts of mineral nitrogen (N-min) found after harvest at 0–60 cm soil depth, were greatest after onions (>60 kg ha^{-1}), followed by peas (ca. 50 kg ha^{-1}). The other vegetable crops left about 30–40 kg ha^{-1} in the soil, whilst the amount after oats was <30 kg ha^{-1}. The amounts found next spring, before fertilization of the following crops, were in the range 40–70 kg ha^{-1}, with about 50–60 % present in the topsoil. Levels had risen, relative to the previous autumn, after mature peas, cauliflower and swedes. There was no change in level after oats, whilst a slight decline had occurred after vining peas and onions.

Fertilizer trials in spring barley (*Hordeum vulgare* L.) and potatoes (*Solanum tuberosum* L.) showed in both years a significant residual benefit of vegetable crops on the yield of the former, but not of the latter crop. It was not possible to detect any difference between the vegetable crops with respect to their fertilizer value. This value was equivalent to the use of ca. 40 kg N ha^{-1} in barley, irrespective of the fertilizer level at which it was compared. More than 70 % of the extra N-min found in the soil in spring after vegetable crops grown the previous year, was recovered in barley plants at harvest. The corresponding figure for potatoes was less than 25 %. This difference between crops was probably due to their contrasting uptake patterns, with later uptake in potatoes than in cereals. This means that leaching early in the growing season is more likely to occur in potatoes than in cereals. Both trials were characterised by higher than normal rainfall in May and June of the succeeding crop years. An analysis of the effect of excess rainfall at this time suggested that one can, under normal conditions for the region, expect a similar after-effect of vegetable crops on potato yields as that found in the case of spring barley.

Zusammenfassung

Es wurden zwei zweijährige Feldversuche auf lehmigen Boden durchgeführt, um die Stickstoffnachlieferung von vier häufig angebauten Gemüsearten (Blumenkohl, *Brassica oleracea* L. var. *botrytis;* Rüben, *Brassica oleracea* L. var. *rapifera;* Küchenzwiebel, *Allium cepa* L.; Erbsen, *Pisum sativum* L. var. *medullare*) im Vergleich mit Hafer (*Avena sativa* L.). zu messen. Die Nachlieferung aus den Gemüsearten wurde sowohl bei Sommergerste (*Hordeum vulgare* L.) als auch bei Kartoffeln (*Solanum tuberosum* L.), die im darauffolgenden Jahr mit vier verschiedenen Stickstoffdüngestufen (0, 40, 80 und 120 kg N ha^{-1}) angebaut wurden, veranschlagt.

Die Menge an Gesamtstickstoff, die in den Ernterückständen gefunden wurde, war bei Blumenkohl (111 kg ha^{-1}) am höchsten und betrug bei den anderen Gewächsen, in absteigender Reihenfolge: 86 kg ha^{-1} in Rüben, 54 kg ha^{-1} in unreifen Erbsen, 42 kg ha^{-1} in reifen Erbsen und 21 kg ha^{-1} in Zwiebeln. Die Menge an mineralischem Stickstoff (N-min), die nach der Ernte in 0–60 cm Bodentiefe gefunden wurde, war nach Zwiebelanbau am höchsten, gefolgt von Erbsen. Die anderen Gemüsearten hinterließen ca. 30–40 kg ha^{-1} im Boden, während die Menge nach Hafer <30 kg ha^{-1} betrug. Die Mengen, die im nächsten Frühjahr vor der Düngung der nachfolgenden Kulturen gefunden wurden,, lagen im Bereich 40–70 kg ha^{-1}, wobei sich ungefähr 50–60 % in der oberen Bodenschicht befanden. Die Mengen waren verglichen mit dem vorherigen Herbst nach reifen Erbsen, Blumenkohl und Rüben erhöht. Es gab keine Veränderung der Menge nach Hafer, während nach unreifen Erbsen und Zwiebeln ein geringfügige Reduktion aufgetreten war.

Die Düngungsversuche mit Sommergerste und Kartoffeln zeigten in beiden Jahren eine signifikant positive Nachwirkung der Gemüsekulturen auf den Ertrag von Gerste nicht jedoch auf den von Kartoffeln. Es war nicht möglich, einen Unterschied zwischen den Gemüsearten hinsichtlich ihres Düngewertes festzustellen. Dieser Wert war äquivalent zur Düngung mit ca. 40 kg N ha^{-1} in Gerste, unabhängig von den Düngestufen bei denen er verglichen wurde. Mehr als 70 % des zusätzlichen N-min, der im Boden gefunden wurde, nachdem

Gemüsegewächse im vorhergegangenen Jahr angebaut worden waren, wurde bei der Ernte in Gerstenpflanzen wiedergefunden. Der entsprechende Wert für Kartoffeln war weniger als 25 %. Dieser Unterschied zwischen den Feldfrüchten war wahrscheinlich auf ihre unterschiedlichen Aufnahmemuster zurückzuführen, wobei Kartoffeln später aufnahmen als Getreide. Dies bedeutet, dass Auswaschungen früh in der Wachstumsperiode mit größerer Wahrscheinlichkeit bei Kartoffeln als bei Getreide auftreten. Beide Versuchsansätze waren während der Folgekultur durch im Vergleich zum Durchschnitt erhöhten Niederschlagsmengen im Mai und Juni gekennzeichnet. Eine Analyse der Effekte von Niederschlagsüberschüssen in diesem Zeitraum legt nahe, dass unter gebietsüblichen Bedingungen eine ähnliche Stickstoffnachlieferung durch Ernterückstände bei Kartoffeln wie im Fall von Sommergerste gefunden worden wäre.

Introduction

It is well established that the residues of many vegetable crops contain large amounts of nutrients, particularly nitrogen (SCHARPF and SCHRAGE 1988, ALT and WIEMANN 1990), and that considerable amounts of mineral nitrogen may also be left in the soil at harvest (EVERAARTS 1993). Many nitrogen recommendation models and expert systems take such factors into account (GREENWOOD et al. 1996, FINK and SCHARPF 1993). Examples of actually measured reductions in the fertilizer requirements of succeeding crops are nevertheless rather scarce.

The value of residual nitrogen is likely to vary according to soil type (moisture retention), climatic conditions (winter leaching and mineralisation rate) and type of succeeding crop (root depth, development rate). More than 200 kg N ha^{-1} was saved over a three year period by taking into account the residual nitrogen from three brassica crops grown on a deep silty soil in E England (RAHN et al. 1992). The fertilizer requirement of spinach was reduced by 30 kg N ha^{-1} after green peas on a sandy soil in NE Germany (FINK 2000). The value of cabbage residues was found in Denmark to be about twice as high for succeeding cabbage crops (90 kg N ha^{-1}) as for leeks (50 kg N ha^{-1}) (NYGAARD SØRENSEN 1993).

Intensive vegetable rotations are disadvantageous due to pest and disease problems, and because it is difficult to achieve a satisfactory nutrient balance when such crops are grown continuously. It is therefore of interest to establish the value of vegetable residues for arable crops. The N-requirement of spring cereals and potatoes was reduced by 50–100 kg N ha^{-1} after cabbage on a loam soil in SE Norway (DRAGLAND et al. 1995). The present study was aimed at establishing the fertilizer value for succeeding arable crops of residues from a range of vegetable crops, when grown on moderately moisture-retentive soil under cool, continental climatic conditions. The vegetables chosen are amongst those most commonly grown in the region. Spring barley and main crop potatoes were chosen as succeeding crops, as they represent crops with different N uptake patterns.

Materials and Methods

Two-year trials were performed in 1995/96 and 1996/97 on humus-rich soil of morainic origin (6 % organic matter, 20 % gravel) at Apelsvoll Research Centre, division Kise, in SE Norway. The soil texture was loam (45 % sand, 40 % silt, 15 % clay) with moderately high available moisture holding capacity (115 mm) within the rooting depth (60 cm). Cauliflower, swedes, onions, peas and oats were grown on two random 20 x 13.5 m plots per trial in the first trial year, and in the second trial year spring barley and main crop potatoes were grown at four levels of N fertilizer (on split plots). Two levels and two timings of N fertilizer use were included for the three first-mentioned vegetable crops. The N rates were 20 % either higher or lower than the current norms, which are 225 kg N ha^{-1} for cauliflower and 135 kg N ha^{-1} for swedes and onion. Application timing was either all at planting (mid May) or two thirds at planting and one third six weeks later. No N was applied to peas, but pea varieties for both vining and maturing were included instead of different N treatments. The average effect of these crops was measured by arranging the second year plots at right-angles to the treatments applied in the first year (i.e. second year plots averaged four first-year N treatments in the three vegetables, and two varieties of peas). Spring oats, which were included as a reference crop, received 90 kg N ha^{-1} at sowing. Adequate levels of P and K fertilizer were applied separately to all crops.

The weather conditions in the trial years are summarised in Table 1, relative to the values normally found at Kise. The first winter (95/96) was colder than normal, and the second (96/97) was milder. There was less rainfall than normal in both winters. On the other hand there was considerably more rainfall than normal in the early summer of both of the years in which fertilizer effects of vegetable residues were measured (+70 mm in May and June). This led to some leaching of the nitrogen present in spring to greater soil depth. The weights of saleable products and above-ground

Table 1. Air temperature and precipitation in the trial period 1995–1997, and normal values for the 30-year period 1961–90 at Kise weather station.
Lufttemperatur und Niederschlagsmengen während des Versuchszeitraums 1995–1997 sowie im 30-jährigen Mittel (1961–90) gemessen in der Wetterstation von Kise.

	Air temperature (°C)		Precipitation (mm)	
Trial year	May–Sept.	Oct.–April	May–Sept.	Oct.–April
1. 1995/6	13.0	–4.4	287	118
2. 1996/7	11.8	–0.4	362	119
3. 1997	14.4	–	328	–
Normal 1961–90	*12.2*	*–2.5*	*309*	*276*

Table 2. Yields of harvested products and N contained in yield products and residues of the vegetable crops. Mean data for two trial years.
Erntemengen, Ernteerträge in DM, N-Gehalt des Erntegutes und der Ernterückstände. Mitterwerte aus zwei Versuchsjahren

	Harvested yield (Mg ha^{-1})	DM of yield (% of FW)	N in products (kg ha^{-1})	N in residues (kg ha^{-1})
Cauliflower	24.5	7.7	53	111
Swedes	72.5	11	93	86
Onions	46.1	12	66	21
Vining peas	0.63	40	115	54
Mature peas	0.66[1]	15	168[1]	44[2]

[1] Measured in one year only, [2] Includes some peas in one year only

Table 3. Amounts of soil mineral N (0–60 cm) found after harvest and in the following spring. Mean data for two trial years.
Menge mineralisiertes N im Boden (0–60 cm) nach der Ernte und im darauf folgenden Frühjahr. Mittelwerte aus zwei Versuchsjahren.

	After harvest (kg ha^{-1})	Following spring (kg ha^{-1})	Change over winter (kg ha^{-1})
Cauliflower	36.7	61.2	+24.5
Swedes	33.6	42.6	+9.0
Onions	64.4	58.5	–5.9
Vining peas	48.5	43.7	–4.8
Mature peas	39.5	62.2	+22.7
Oats	28.2	31.7	+3.5

residues of all crops were measured. Root residues, excluding small fibrous roots, of cauliflower were also measured. Plant nitrogen contents were determined by Skalar autoanalyser following sample drying at 80 °C. All plots were sampled to a depth of 60 cm shortly after harvest, and again in spring before fertilization of next year's crop, for the determination of their mineral nitrogen content (nitrate and ammonium). Samples were frozen and analysed by means of Aquatec autoanalyser after extraction in 1 M KCl.

Analyses of variance were performed using software described by NISSEN and MOSLETH (1985). Calculations of expected leaching from various soil depths were made using the equation given by BURNS (1976). This equates the fraction of nitrate leached (f) to the soil's field capacity (Fc), to the amount of water percolating through (P), and to an exponent (x) related to the depth of incorporation within the soil, as $f = (P/(P+(Fc/100)))^x$.

For surface applied nitrate x = h, where h is the depth to which leaching is calculated. For nitrate evenly distributed within the profile x = 0.5 h. For nitrate incorporated to depth d (less than h), x = h – 0.5 d.

Results

N in vegetable residues and in soil

The yield level of the vegetable products removed, their N content, and the N remaining in residues left on the field, are shown in table 2. There were relatively high amounts of N in cauliflower and swede residues, equalling at least half of the amounts applied as N fertilizer. The amount of N in pea haulm was intermediate and that in onion leaves was low. The N in oat straw was not measured, but may be assumed to have been no more than 20 kg ha^{-1}.

The highest amount of mineral N in the soil after harvest was found following onions, where it equalled almost half of the N applied (table 3). An intermediate amount was found after vining peas, whilst after the other vegetable crops the amounts exceeded that found after oats by no more than 10 kg N ha^{-1}. By the following spring, net increases in mineral N of 20–25 kg ha^{-1} had occurred after cauliflower and mature peas, and there was a smaller increase after swedes. Slight net declines had taken place after onions and vining peas. The proportion of mineral N found in the topsoil (0–25 cm) was on average 45–60 % of the total, both in autumn and spring. The proportion varied somewhat been years, being lower (30–50 %) in 1996 than in 1997 (60–80 %). This is of relevance for its subsequent availability to crops.

Yield and N uptakes of succeeding crops

Yields of both barley and potatoes were reasonably high, despite difficult establishment conditions, due to high rainfall in the spring of both years. Mean effects of the previous crops, averaged over all N fertilizer levels, are shown in table 4 for yield, quality and N uptake.

All the vegetables had a positive effect on barley yield, relative to growing oats the year before. The effect was more marked in 1997 than in 1996, despite lower precipitation the first winter, and was seen in both grain and straw. The yield increase was about 20 %, averaged over all fertilizer levels, and differences between vegetable crops were small and non-significant. After both cauliflower and onions the moisture content in straw was markedly higher than after oats, suggesting that nutrients may have been released later in the growing season after the former crops. Nitrogen concentrations in grain and straw were higher after vegetables in some cases, and total N uptakes were increased by 14–21 kg ha^{-1} (25–38 %), relative to oats.

In the case of potatoes there was little overall effect of the previous crop, but there was indication of an interaction between years ($p < 0.06$). Whilst in 1996 there

Table 4. The effect of previous crops on yields and N-uptake of spring barley and potatoes, compared with growing oats the year before. Mean data for two years and four N levels.
Vergleich der Wirkung von Gemüsearten bzw. Hafer als Vorkultur auf den Ertrag und die N-Aufnahme von Gerste und Kartoffeln. Mittelwerte aus zwei Versuchsjahren und vier N-Düngestufen.

Previous crop:	Oats	Peas	Swedes	Caulifl.	Onions	P level	$LSD_{5\,\%}$
BARLEY							
$Grain_{15\,\%,}$ Mg ha^{-1}	3.86	+0.74	+0.74	+0.71	+0.95	<0.001	0.41
Moisture %	10.7	−0.1	−0.3	−0.3	−0.3	<0.08	(0.5)
$Straw_{15\,\%,}$ Mg ha^{-1}	2.28	+0.57	+0.47	+0.58	+0.60	<0.01	0.32
Moisture %	18.6	−2.0	−2.0	+2.0	+3.9	<0.001	4.0
N % in grain	1.46	+0.04	+0.13	+0.09	+0.13	<0.04	0.09
N % in straw	0.40	−0.02	−0.02	+0.04	+0.01	<0.08	(0.05)
N uptake, kg ha^{-1}	55.2	+13.9	+16.0	+16.5	+20.6	<0.001	7.2
POTATOES							
Tuber yield, Mg ha^{-1}	28.54	+1.31	+0.14	−0.07	−1.18	>0.1	(3.12)
Dry matter %	21.2	−0.8	−0.4	−0.4	−0.4	<0.02	0.5
N % in tubers	0.89	+0.06	+0.07	+0.13	+0.14	<0.02	0.09
Tuber N uptake, kg ha^{-1}	53.9	+4.5	+4.3	+7.3	+5.2	>0.1	(10.0)

was no effect, the mean yield after vegetables increased by 10 % in 1997, relative to that after oats. Tuber dry matter concentrations were slightly lower after vegetables, and tuber nitrogen concentrations were somewhat higher after cauliflower and onions. Both findings suggest that nutrient supply was affected by previous cropping. However the increases in N uptake in potato tubers were mostly below 5 kg ha^{-1}.

Yields of both barley and potatoes showed significant increases ($p<0.01$) up to the highest N fertilizer level used (120 kg ha^{-1}). There was no significant interaction between the effect of N fertilizer level and previous cropping. In the case of barley, the responses after the various vegetables were very similar, and the average response is shown in fig. 1, relative to oats. The fertilizer value of vegetable residues for barley may thus be seen to be equivalent to about 40 kg N ha^{-1}, irrespective of fertilizer level. The absolute increases in grain yield ascribable to vegetable residues were 1.23 Mg ha^{-1} in the absence of fertilizer, 0.92 Mg with 40 kg N, 0.57 Mg with 80 kg N and 0.43 Mg with 120 kg N. Similar comparisons in potatoes showed that yields tended to increase in the absence of N fertilizer, but not otherwise.

Nitrogen uptake increased almost linearly with increasing N fertilizer level in both barley plants and potato tubers. In both crops the uptakes were higher after vegetables than after oats, by about the same amount at all fertilizer levels (fig. 2).

Discussion

The amount of nitrogen in above ground plant residues was greatest after cauliflower, relatively large after swedes, intermediate after peas and small after onions. Only 7 kg N ha^{-1} was found in cauliflower roots, and very little was likely in the remaining roots of swedes or onions. Considerably more might be expected in pea root nodules, but this was not measured in the present study. Of prime agronomic interest is the speed with which the residue N becomes available to following crops. A rule of thumb used in Switzerland is that 20 % of vegetable residue N is available the following year (Chr. GYSI, personal comm.). In the present case this would imply 30 kg N ha^{-1} after cauliflower, 20 kg after

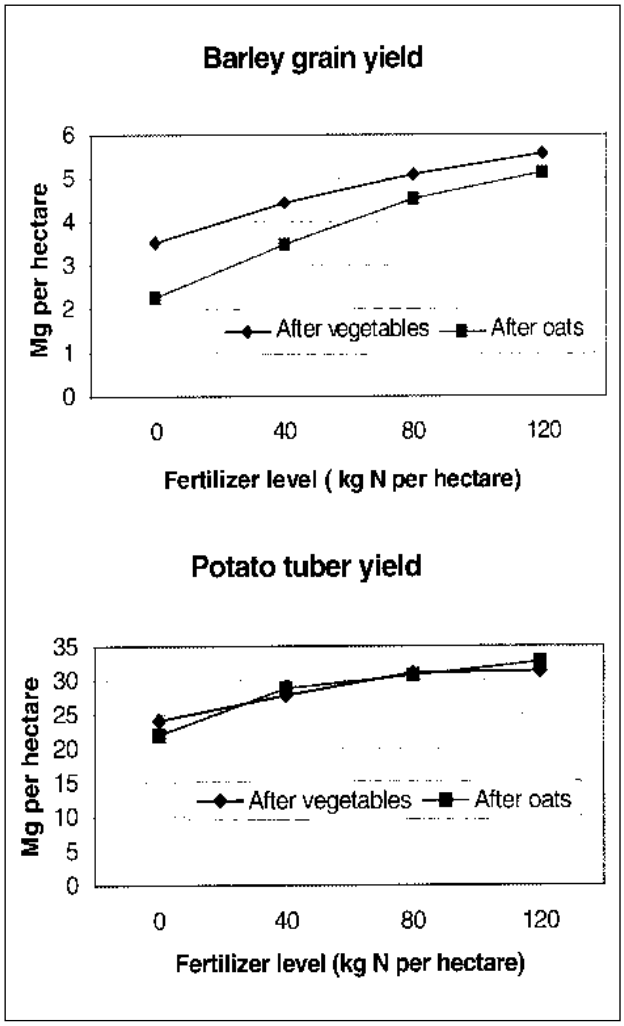


Fig. 1. Yields of barley grain and potato tubers with increasing amounts of N fertilizer after different types of crop. Mean data for 1996–97. (Vegetables = means of peas, cauliflower, swedes and onion).
Zusammenhang zwischen Gerste- und Kartoffelerntemengen, ansteigenden N-Düngestufen und der Vorkultur mit verschiedenen Gemüsearten (Erbsen, Blumenkohl, Rüben und Küchenzwiebel). Mittelwerte der Jahre 1996–97.

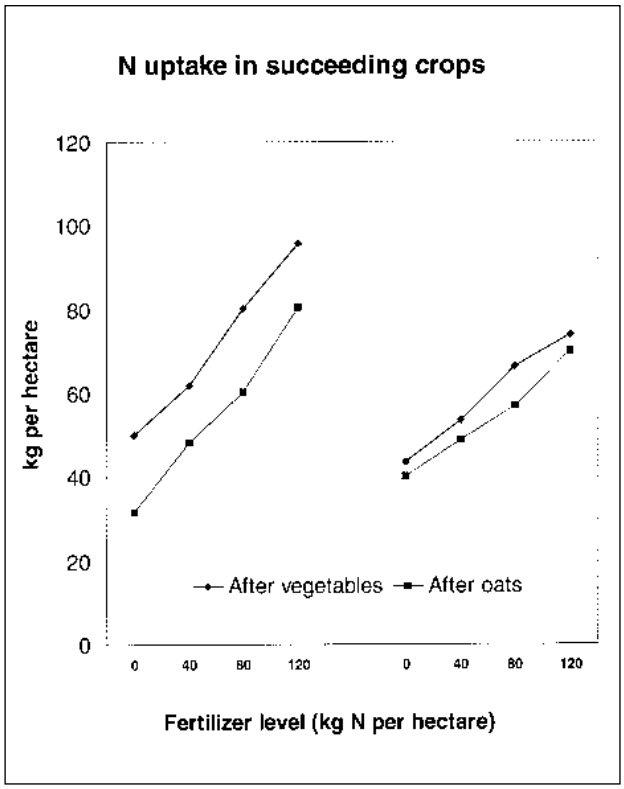


Fig. 2. The uptake of nitrogen in whole barley plants (left) and in potato tubers (right) with increasing use of N fertilizer after oats and after vegetables. Mean data for 1996–97.
Die Stickstoffaufnahme von Gersten- (links) und Kartoffel-(rechts) - Gesamtpflanzen bei ansteigenden N-Düngegaben und bei Vorkulturen mit Hafer und Gemüsearten. Mittelwerte aus 1996–97.

swedes and <5 kg after onions. Field incubation studies at Kise suggested, however, that the release of N from many materials is quite rapid (HENRIKSEN and BRELAND 1999). After only 200 days (the first winter and spring) about 60 % had been released from clover, 40 % from cabbage residues, 30 % from potato haulm, 20 % from ryegrass and less than 20 % from barley straw. German experience indicates even more rapid breakdown of leafy vegetable crops, with up to 80 % being released within 6–8 weeks in for example spinach and leeks (SCHARPF and SCHRAGER 1988). How much of this remains available to succeeding crops depends on how much either becomes immobilised by microbes or is lost to leaching or to the atmosphere.

Measurements of mineral N in soil showed highest residues after onions, which is natural in view of this crop's low N uptake. Some of this nitrogen was lost over winter, whereas in the case of the other vegetables, levels usually increased somewhat by next spring. The increase was greatest after mature peas and cauliflower, representing about 50 % and 15 %, respectively, of the amounts present in their residues in autumn. The corresponding figure for swedes was <10 %. Some of the nitrogen released may, however, already have been leached before sampling. If one assumes the same proportion to have been leached as the decline in mineral N found after onions, the total amounts released (% of N in residues) were probably in the order of 70 % after peas, 20–30 % after cauliflower and 15–20 % after swedes.

The fertilizer responses in the second trial years showed reduced N requirements after vegetables in the case of barley, but not in potato. Barley plants took up 74 % of the extra reserve of mineral N found in the soil after vegetables, relative to oats, whilst potatoes took up only 23 %. The most likely explanation for this difference lies in the crops' contrasting N uptake patterns. Studies at Kise have shown that, even when these crops are planted at the same time, the N uptake of potato starts about one month later than that of barley, and does not match it until a further month has passed (Egil EKEBERG, unpublished data). This finding corresponds with observations on the root growth of the two crops (RILEY 1989). Excess precipitation early in the growing season is thus more likely to cause leaching in potatoes than in cereals.

There was in both trial years (1996 and 1997) greater rainfall than normal in May and June, whilst the potential evaporation (Ep) was lower than normal. The soil moisture level at Kise normally remains at field capacity until the end of April. The amount of excess rainfall in May and June is thus rainfall minus actual evaporation over the same period. In the case of potatoes the latter is about 50 % of Ep at this time, whilst for cereals it is about 75 % (RILEY 1989). The excesses calculated on this basis for the trial years are shown in table 5. The rainfall excesses were found to be 70–80 mm greater than normal in both years.

It is also of interest to compare these values with those for 1992 and 1993, when large fertilizer effects of cabbage residues were found in both wheat and potatoes (DRAGLAND et. al 1995). There was a considerable rainfall deficit in May and June in 1992 (–61 mm for potato), and a smaller excess than normal in 1993 (23 mm). A treatment with no fertilizer N gave 12.2 Mg ha^{-1} (+37 %) higher potato yield after cabbage than after barley in 1992, and 6.9 Mg ha^{-1} (+22 %) in 1993, whereas the average increase after vegetables in the present trial was only 2.1 Mg ha^{-1} (+9 %). Plotting these three figures against rainfall deficit/excess in May and June reveals a linear relation, and suggests by interpolation that one may expect, under normal conditions for potatoes with 30 mm rainfall excess in May and June, a yield increase of 6.0 Mg ha^{-1} after vegetables. This is about the same increase as that obtained with the use of 60 kg N ha^{-1} after oats (fig. 1).

Table 5. Excess rainfall in May–June in the experimental years and the 30-year normal
Regenüberschuß von Mai–Juni in den Versuchsjahren und im 30-jährigen Mittel.

	Rainfall	Potent. evaporation	Excess in cereals	Excess in potato
1996	177 mm	153 mm	62 mm	101 mm
1997	173 mm	135 mm	72 mm	106 mm
30-year normal	103 mm	146 mm	–7 mm	30 mm

Table 6. Proportions (%) of mineral N likely to be leached from the upper (0–30 cm) and whole (0–60 cm) zones of 3 soil types at increasing levels of excess rainfall over evaporation. Calculated after BURNS (1976), assuming Fc = 93 mm, 167 mm and 245 mm, respectively.
Anteil des mineralisierten N in %, der bei drei Bodenarten und ansteigendem Regenüberschuß aus der oberen (0–30 cm) bzw. der ganzen (0–60 cm) Wurzelzone ausgewaschen wurde. Berechnungen nach BURNS (1976) unter der Annahme, daß Fc= 93 mm, 167 mm bzw. 245 mm.

	Mineral N applied on soil surface						Mineral N evenly distributed in soil					
Rainfall	Sand		Loam		Silty clay		Sand		Loam		Silty clay	
excess	0–30	0–60	0–30	0–60	0–30	0–60	0–30	0–60	0–30	0–60	0–30	0–60
50 mm	37	18	18	5	9	1	61	43	43	21	30	10
100 mm	61	43	42	21	29	10	78	65	65	46	54	32
150 mm	72	57	56	35	43	21	85	75	75	59	66	46

The significance of rainfall deficit or excess for leaching is of course dependent upon both the soil's capacity for water storage (field capacity) and the distribution of nutrients within the soil profile. The greater the field capacity and the closer nutrients are to the surface, the higher the rainfall excess must be before leaching takes place, as indicated by the Burns equation. The mineral N in spring was found to be distributed fairly evenly between topsoil and subsoil, and the normal excess rainfall for potatoes in May and June (30 mm) would not be expected to give much leaching, even on sandy soil. However, an excess of 100 mm on loam soil, as experienced in the present case, would be expected to lead to leaching of 65 % of the mineral N from the topsoil layer and 46 % from the whole root zone (60 cm). Corresponding proportions for sandy and silty clay soils (RILEY 1996) are 80 %/65 % and 54 %/32 %, respectively (table 6).

This confirms that the low response to vegetable residues found here in potatoes was probably due to excess rainfall during the early summer of the trial years. A similar response to that found in barley might be expected in a more normal year in inland regions of Norway. In areas with more rainfall, such as the coastal region of southern Norway, much of the soil mineral N derived from previous crop residues may be leached even earlier, before the start of the growing season, as reported by GUTTORMSEN (2000). Soil type was found to be important even there, however, with considerably lower winter leaching from loam soil than from sandy soil. If growers measure the amount and distribution of soil mineral N at planting, and have information on soil type and expected rainfall balance during early growth, they may use the data given in table 6 to estimate the likely utilisation of mineral N by crops.

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Anschrift des Verfassers: Hugh Riley, Norwegian Crop Research Institute, Apelsvoll Research Centre, Norway