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The growth and development of carrot roots

Das Wachstum und die Entwicklung der Mohrrübe

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Summary

The growth and root development of carrots was studied by means of X-ray computed tomography. Carrots were grown in a phytotron at constant diurnal temperatures 9, 12, 15, 18, and 21 °C, in natural daylight during the period June 21 – December 13, 1995. Pictures were taken every 10–11th day during a three month period. Root length increased most at 9 and 12 °C, and less at 21 °C. A termination of the root tip was observed after 45 days at all temperatures except for carrots grown at 9 °C. However, root length continued to increase until harvest. At 9 and 12 °C the root length increased partly by means of a formation of bulbs which later became part of the carrot root. This phenomena was most pronounced at 9 and 12 °C, and could also be observed at 15 °C, but not at 18 and 21 °C. At 18 and 21 °C root growth seemed to occur more smoothly by a slow increase in thickness of the root's lower part. The experiment shows that the growth of the carrot root is a continuous process. Thus, a carrot root with a wellrounded root termination might continue to grow if growing conditions are favourable.

Zusammenfassung

Das Wachstum und die Entwicklung der Mohrrübe wurde mit Hilfe der Röntgen-Computer-Tomographie (CT) untersucht. Die Mohrrüben wurden vom 21. Juni bis zum 13. Dezember 1995 bei konstanten diurnalen Temperaturen von 9, 12, 15, 18 und 21 °C im Phytotron unter natürlichen Außenlichtbedingungen kultiviert. Die CT-Abbildungen wurden im Abstand von 10 bis 11 Tagen über einen dreimonatigen Zeitraum erstellt. Die Wurzellänge nahm am stärksten bei Wachstumstemperaturen von 9 und 12 °C und am geringsten bei Temperaturen von 21 °C zu. Bei allen Temperaturbedingungen mit Ausnahme von 9 °C wurde ein Abschluß der Wurzelspitzenentwicklung nach 45 Tagen festgestellt. Die Gesamtwurzellänge stieg bis zum Erntetermin jedoch noch weiterhin an. Unter Temperaturbedingungen von 9 und 12 °C stieg die Wurzellänge teilweise durch die Entwicklung von Knollen an der Wurzelspitze an, die später mit der eigentlichen Mohrrübe zusammenwuchsen. Dieses Phänomen wurde in der Hauptsache bei Wachstumstemperaturen von 9 und 12 °C beobachtet, trat teilweise auch bei 15 °C auf, nicht jedoch bei 18 und 21 °C. Unter Wachstumsbedingungen von 18 und 21 °C schien das Wurzelwachstum gleichmäßiger zu verlaufen. Es kann als eine langsame Verdickung des unteren Bereichs der Wurzel beschrieben werden. Die hier beschriebenen Versuche zeigen, daß das Mohrrübenwachstum ein kontinuierlicher Prozess ist. Demzufolge könnten gut entwickelte Mohrrüben mit abgerundeten Wurzelspitzen unter günstigen Wachstumsbedingungen weiter wachsen.

Introduction

The growth of carrot roots has scarcely been subject of investigations during the recent years, because growth parameters like root weight, length, diameters have been previously thoroughly investigated by earlier investigators (ESAU 1940, BLEASDALE and THOMPSON 1963, BANGA and DE BRUYN 1964). However, none of the earlier scientists were able to follow the continuous growth of carrots over time by means of non-destructive methods. Measuring carrots from a plant population implies that a new carrot has to be assessed each time. By assessing physical and chemical parameters of a certain amount of carrots at each time of harvest, we presume to be able to reconstruct the growth of a carrot root over time, but we will never know how the carrot would have grown if not pulled. It is also commonly believed that after a carrot root having reached a certain length – at least for certain cultivars – the root tip terminates and becomes rounded. Thereafter no further increase in root length occurs. But is this true? How do carrots really grow when not disturbed? The question is not easy to answer because once a carrot has been pulled off the ground its taproot is damaged and length-growth ceases.

In this paper the continuous growth and development of carrot roots is studied by means of X-ray computed tomography. Using this non-destructive method carrot growth was studied with minimal disturbance of the plants. Such studies are of some commercial importance because a certain degree of physiological development or 'ripeness' – as some authors express this stage – is desirable for carrots for fresh consume as well as for storage. Terms like 'cylindricity' or 'rounding of the root tip' are often used as a measure for a root being ready for harvest. Therefore emphasis was laid on the growth of the root tip during later stages of the root's physiological development.

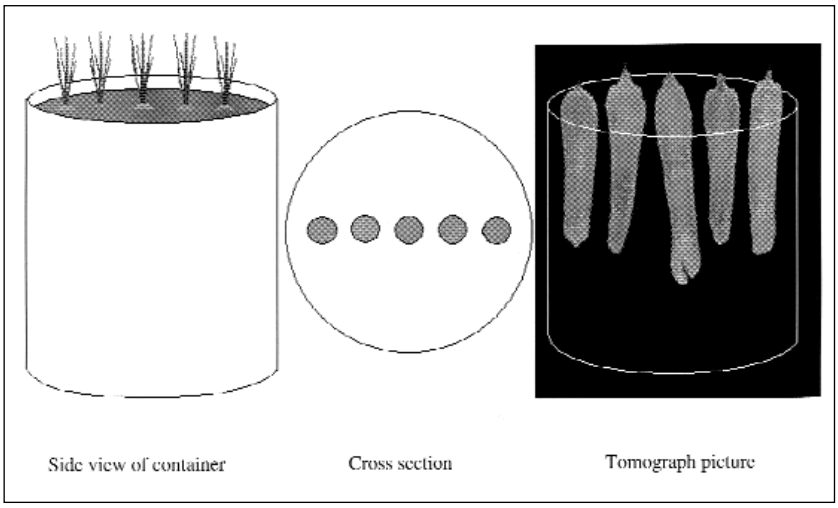


Figure 1. Method of imaging pictures by means of computer tomography
Methode der bildlichen Wiedergabe mit Hilfe der Computer-Tomographie

Materials and Methods

Growing conditions

Experiments with carrots grown in controlled climate chambers (phytotron) were carried out in 1995 at the Agricultural University of Norway. Carrots of the variety 'Panther F_1' (Sluis & Groot, Holland) were grown in white 10 litre polythene containers (surface 491 cm^2, height 26 cm) filled with fertilised peat (Nittedal Torvindustri, Kongsvinger, Norway). The carrots were sown on May 20 and raised during four weeks in a growth chamber at 20–22 °C, and 16 hours artificial fluorescent light, 30–45 E m^{-2}. The number of seedlings was adjusted to only five plants per container, arranged on a line across the container. One container was placed at each of the constant diurnal temperatures 9, 12, 15, 18, and 21 °C, in daylight cells on June 21. The temperatures at the phytotron were controlled to ±0.5 °C, and a water vapour pressure deficit corresponding to 4 mm Hg was maintained at all temperatures. The experiment was performed parallel to the one described by ROSENFELD (1998).

The plants were watered approximately every second day, according to their consumption of water, which varied with temperature and solar radiation. The amount of water given was measured by weighing the containers and water was added to a certain weight. Because of the increase in root weight a compensation of water due to increasing root weight was given after 40 and 70 days of growth. The amount of water given each time was then increased with 250 ml. N-P-K fertiliser (15-4-12, Hydro), 4.5 g per container and dolomite lime, 10 g per container, was added every four weeks during the growing period. Images of the carrots were taken every 8-11th day, as shown in Table 1.

Table 1. Dates for X-ray computed tomography-imaging carrot roots from start of the experiment to the respective date of imaging. The carrots were sown on May 20.
Termine für die Computer-Tomographie von Mohrrübenwurzeln. Die Möhren wurden am 20. Mai ausgesät.

Image no.	Date 1995	Days from start of experiment in the phytotron
Start	June 21	1
1	July 04	13
2	July 13	23
3	July 24	33
4	August 04	44
5	August 14	54
6	August 24	64
7	September 01	72
8	September 11	83
9	December 13	176

Computer tomography

X-ray computed tomography (CT) was used to visualise the growing carrot roots.

The containers were removed from the growth chambers and transported carefully to the site of CT-imaging, approximately 300 m from the phytotron, at the Department of Animal Genetics and Breeding at the Agricultural University of Norway. One container from each growth chamber/temperature was used for CT. Marks on the container indicated the exact point for X-ray measurements, as a cross-line from left to right, always in the same position (Figure 1). Because the carrot plants were not always growing in an exact line vertically, several images were taken with one-millimetre intervals to cover the centre of the entire root. Out of the five roots one was chosen to show its growth from July 4th to December 13. The process of CT-imaging took approximately one hour each time. Thereafter the containers were returned to their original growing sites at the phytotron.

The computer tomograph was a Siemens Somatom 2 whole-body scanner, working according to the fan-beam principle. The X-ray tube is rotated around the object in the cross sectional plane while pointing trough the centre of the cross section. During one full rotation fan-shaped X-ray pulses are fired from 360 different angels (BENTSEN and SEHESTED 1989, MEBERG et al. 1999). Each pulse was recorded by 512 detectors on the opposite side of the object. One full rotation scan results in 360 x 512 = 184.320 transmission records. The exposure time was 5 seconds. The density matrix produced by the CT-scanner includes values in the range minus 1024 (no absorption) to plus 1023 (total absorp-

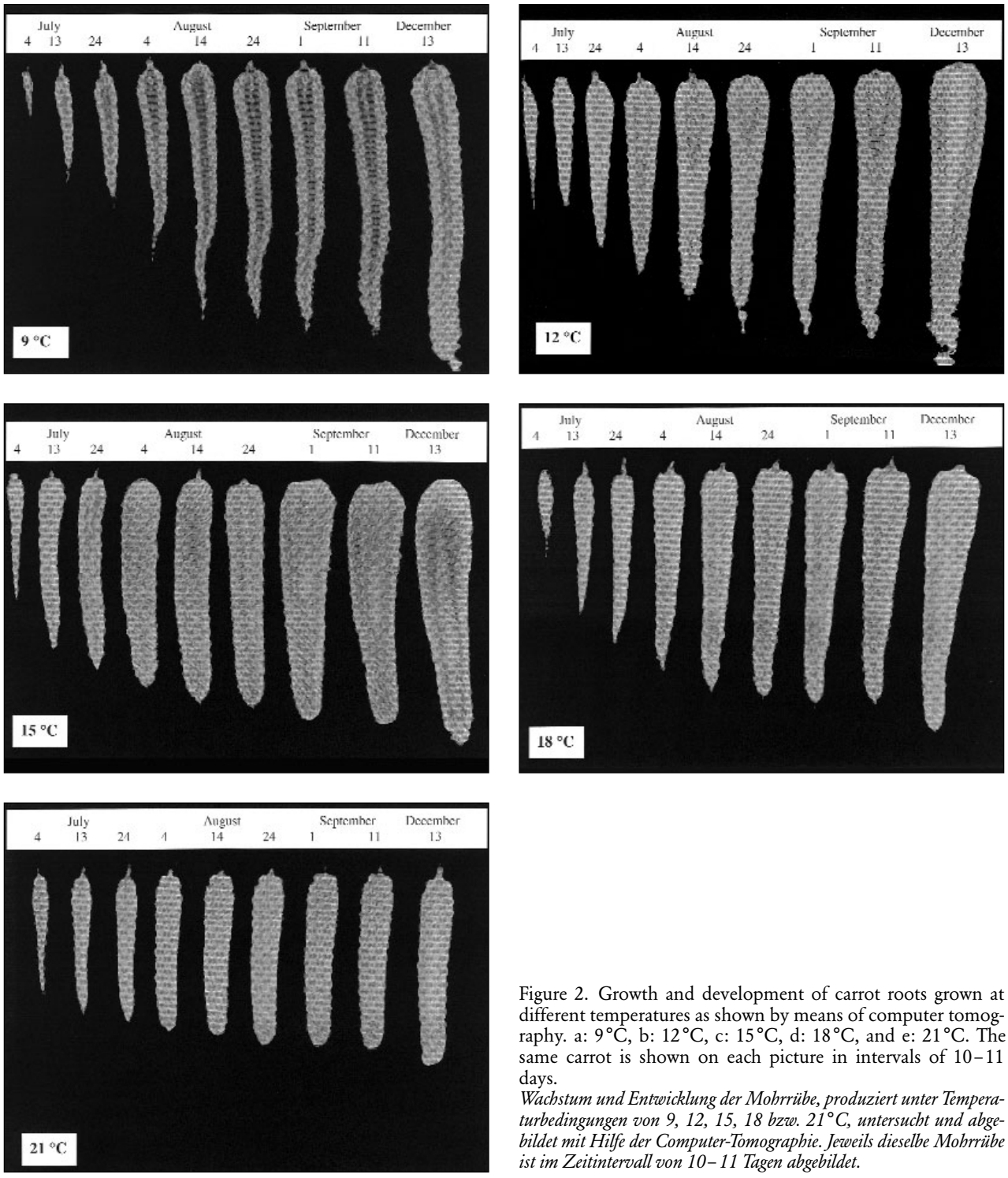


Figure 2. Growth and development of carrot roots grown at different temperatures as shown by means of computer tomography. a: 9 °C, b: 12 °C, c: 15 °C, d: 18 °C, and e: 21 °C. The same carrot is shown on each picture in intervals of 10–11 days.
Wachstum und Entwicklung der Mohrrübe, produziert unter Temperaturbedingungen von 9, 12, 15, 18 bzw. 21 °C, untersucht und abgebildet mit Hilfe der Computer-Tomographie. Jeweils dieselbe Mohrrübe ist im Zeitintervall von 10–11 Tagen abgebildet.

tion). It can be treated as a 256 x 256 image consisting of 2048 levels of grey, where 11 bits are used to present each picture element (pixel). The CT-scanner was calibrated before each sampling by scanning a water-filled object to produce a phantom image. Water has CT-value 0, and the pixel values were added a correction factor equal to the mean value of the phantom image. The actual size of the pixels depends on the zoom factor (z) of the scanner, which was held at the same values throughout the entire experiment (z = 2 mm per pixel). The CT-values were transformed into cross section images, shown in Figure 1.

CT-images of the growing carrots were performed approximately every tenth day. The last image was intended to be taken at the end of September, but due to technical problems the imaging was postponed to December 13th. The containers were kept at their respective temperatures at the phytotron during this period. Artificial light (35 E m^{-2} photosynthesis active radiation PAR) high pressure sodium vapour lamps (Son T 400),

was added during September–October, 4 hours a day and 8 hours a day during November–December. The natural light conditions during the latter period were poor, the entire photosynthesis active radiation (PAR) for November–December 13th was equal to that of one week in July.

The experiment was conducted parallel to the one described by ROSENFELD (1998).

Results and Discussion

Pictures of the growing carrots are presented in Figures 2a–e. Root length increased more at the lower temperatures (9 and 12 °C) than at the higher temperatures (18 and 21 °C) as previous shown by ROSENFELD et al. (1998). A rapid increase in root growth occurred during the period July 4th to August 14th, thereafter the increase in root length was much slower and seemed to have terminated at September 11th. However, three month later, at the last date of CT-imaging (December 13th), root length and size had increased considerably. Especial interesting is the increase in root length at 9 and 12 °C (Fig. 3a and b). Seemingly a termination of the root tip was achieved at August 4th (12 °C), but ten days later a tuber was formed at the root tip, which continued to grow and gained in size and weight. At December 13th the tuber was part of the root and a new bulb started to grow. This phenomena was most pronounced at 9 and 12 °C, and could also be observed at 15 °C, but not at 18 and 21 °C. At the latter temperatures growth of the root tip occurred more smoothly by thickening of the tap root. None of the roots at any of the temperatures were bolting or had visible flower buds by the middle of December (Figure 4).

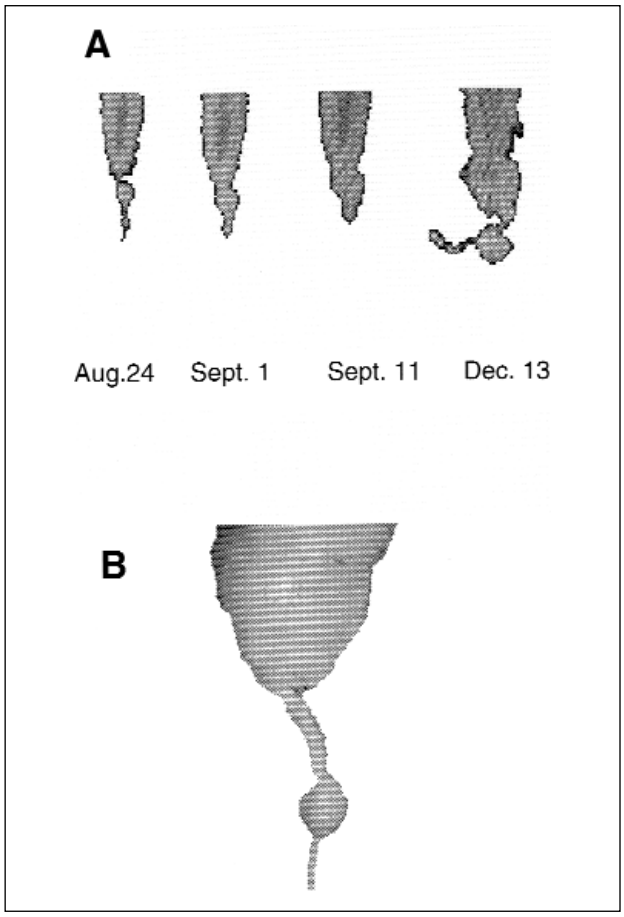


Figure 3. Root termination of carrot roots grown at 12 °C. A: Development of the root tip as shown by means of computer tomography. B: photography of tuber formation at the root tip.
Wurzelabschluß der Mohrrüben, die bei 12 °C gewachsen sind. A: Entwicklung der Wurzelspitze, untersucht und abgebildet mit Hilfe der Computer-Tomographie. B: fotografische Abbildung der Knollenbildung an der Wurzelspitze.

Maturity – ripening

The function of the carrot root for its own purpose is to be an organ of stored energy, to produce a seed stalk for reproduction. The formation of a seed stalk is dependent of vernalizing temperatures over a certain time, and might also occur in quite small roots. For man the carrot serves as a source of carbohydrates and vitamin A, and other components of nutritional value. It is in connection with the development of these components we speak in terms of maturity. 'Maturing' in carrot roots is by some authors characterised as 'a tendency for the root to become smoothly thickened over the whole length and well-rounded at the tip and to become more coloured' (BANGA and DE BRUYN 1964). However, to refer to 'maturing' of a root is a subjective term, mostly connected to a specific application, such as for fresh consume, for storage, processing or for seed production. Ripening is the process that leads to maturity and can only be meaningful when a final stage of development or chemical composition is reached. Such stages were not reached in any of the roots grown at any of the temperatures, as root growth continued throughout the whole experiment.

When using the cylindricity or root termination (ROSENFELD 1998) as quality criteria or stage for carrots to be ready for harvest, one must be aware of that the cylindricity and root termination of a carrot root is not a final stage, as this experiment shows. The cylindricity of a carrot root changes with age and carrots might even become more pointed at their root tips for a period, depending on growing conditions. An increase in root-shoulder width at 12, 15 and 18 °C (Figure 2b, 2c and 2d) will also lead to a decrease in cylindricity after a certain stage of development, as stated by ROSENFELD (1998).

The practical conclusions of this experiment, are that carrot roots grown in mild climate usually will obtain a good root termination, but lower temperatures accompanied with good light conditions at the end of the growing season, might cause the root tip to continue to grow, resulting in a more pointed root shape. If such pointed root shape is undesired, the roots should be harvested as soon as root size and root termination is satisfactory.

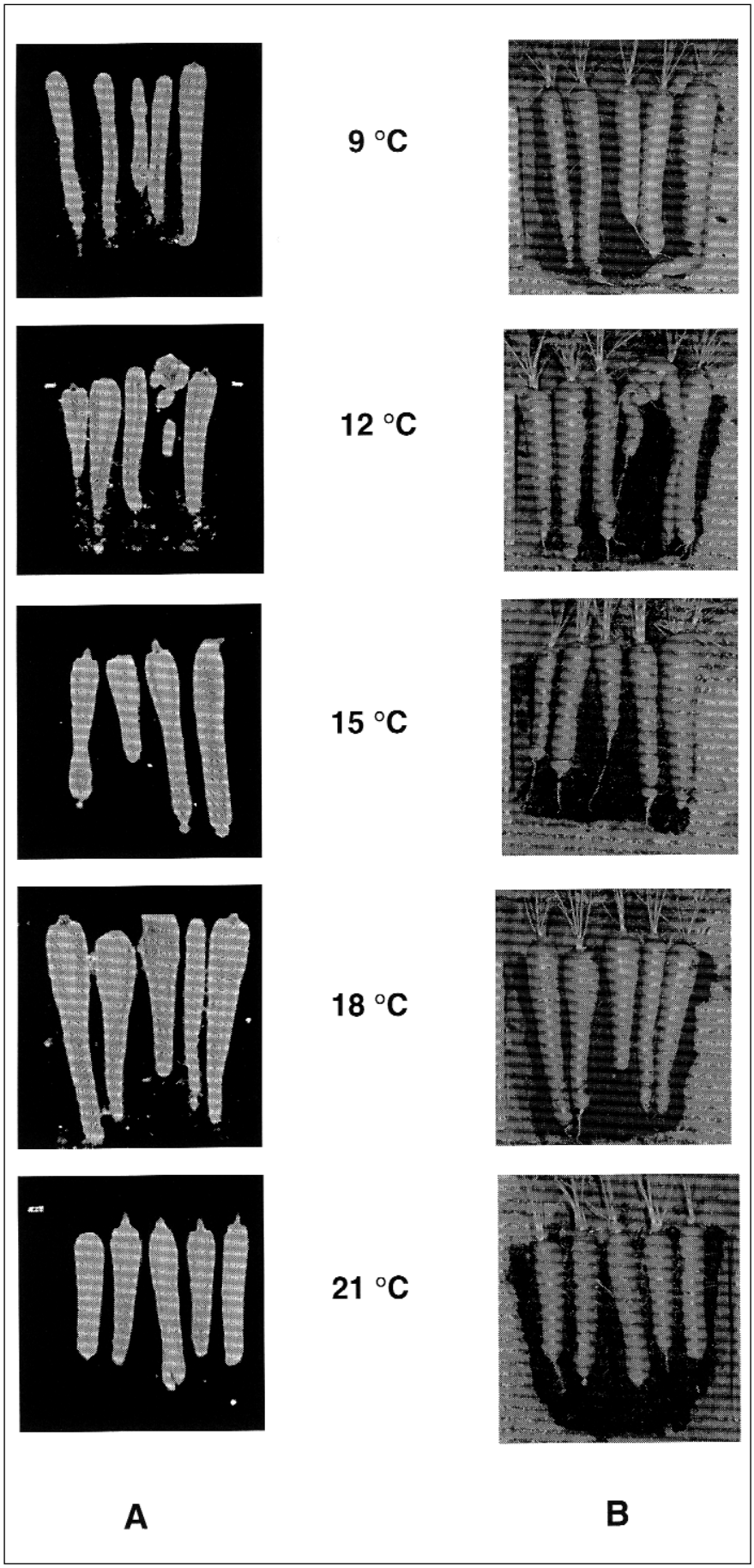


Figure 4. A: Images taken in the middle of December by means of computer tomography. Carrots grown at 9, 12, 15, 18 and 21 °C. B: Photographs of the same carrots. The root to the left at 15 °C was not in line with the other and could not be shown by computer tomography.
A: Bildliche Wiedergabe von Mohrrüben produziert unter Temperaturbedingungen von 9, 12, 15, 18 bzw. 21 °C. mit Hilfe der Computer-Tomographie, Abbildungen von Mitte Dezember. B: Fotografien der selben Mohrrüben. Bei 15 °C wurde die linke Wurzel nicht von der Computer-Tomographie erfasst.

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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

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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

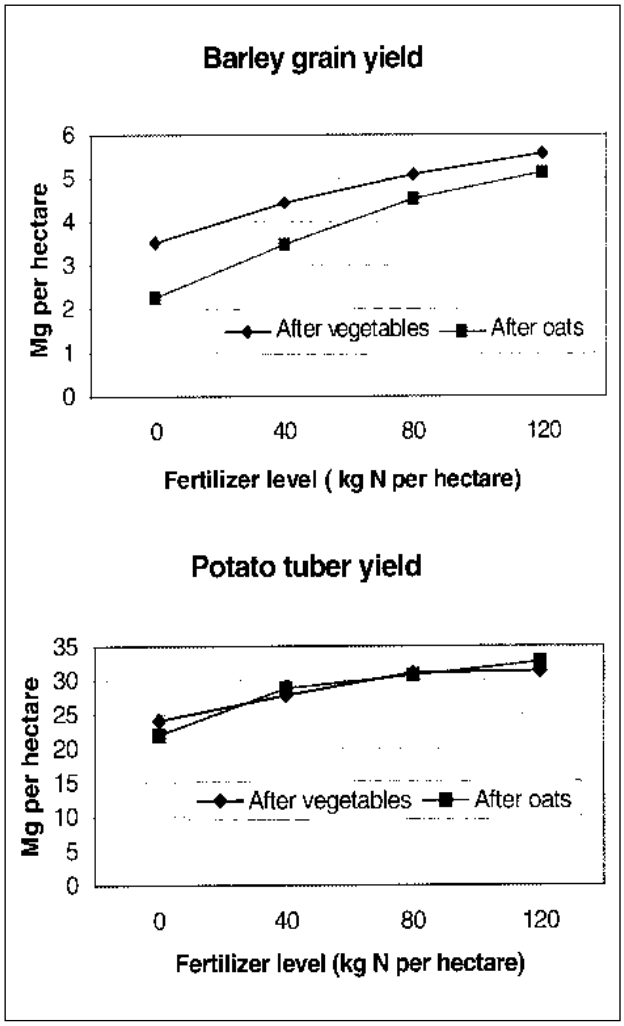


Fig. 1. Yields of barley grain and potato tubers with increasing amounts of N fertilizer after different types of crop. Mean data for 1996–97. (Vegetables = means of peas, cauliflower, swedes and onion).
Zusammenhang zwischen Gerste- und Kartoffelerntemengen, ansteigenden N-Düngestufen und der Vorkultur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

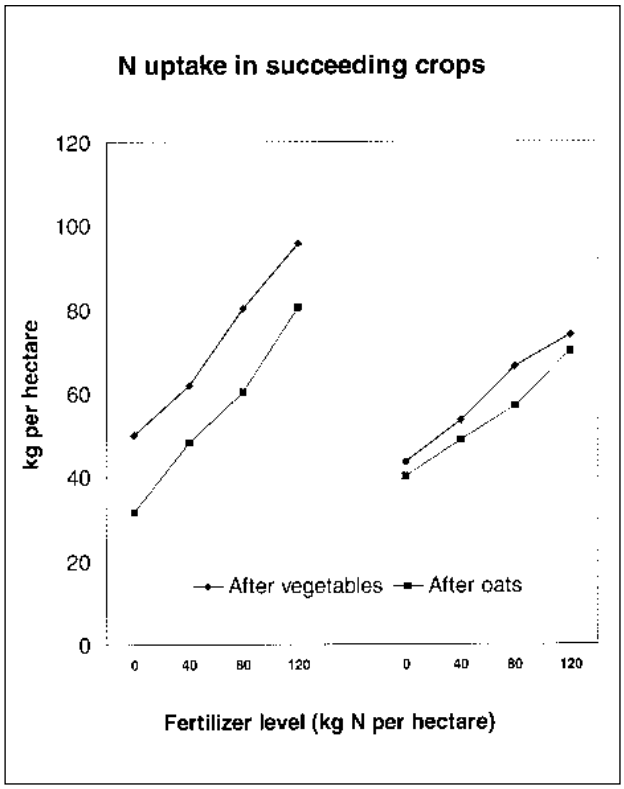


Fig. 2. The uptake of nitrogen in whole barley plants (left) and in potato tubers (right) with increasing use of N fertilizer after oats and after vegetables. Mean data for 1996–97.
Die Stickstoffaufnahme von Gersten- (links) und Kartoffel-(rechts) - Gesamtpflanzen bei ansteigenden N-Düngegaben und bei 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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Effect of Nitrogen Fertilization on Growth, Yield and Nitrogen Contents of Radishes

Wirkung von Stickstoffdüngung auf Wachstum, Ertrag und Stickstoffgehalt von Rettich

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Summary

In this research, the effect of usual and an excessive amount of nitrogen fertilization on the growth, yield and nitrogen content of five different radish (*Raphanus sativus* L.) genotypes commonly grown in Turkey were investigated. The nitrogen fertilization at the rates of 0, 100 (usual) and 200 (excess) kg ha^{-1} were applied under the field conditions.

No significant effect was determined among the nitrogen doses in terms of number of leaf per plant in radish. The highest root diameter, length, weight and yield were obtained from 200 kg N/ha treatments. On the other hand, total nitrogen and nitrate content of the roots increased with increasing the nitrogen doses. Therefore, normal nitrogen doses should be applied in these radishes to have better yield and healthy crops.

Zusammenfassung

In dieser Arbeit wurde der Einfluss von durchschnittlicher und stark erhöhter Stickstoffdüngung auf das Wachstum, den Ertrag und den Stickstoffgehalt von fünf Rettich-Genotypen, die in der Türkei verbreitet angebaut werden, untersucht. Die Stickstoffdüngung mit unterschiedlichen Mengen (0, 100 und 200 kg ha^{-1}) wurde unter Feldbedingungen durchgeführt.

Die Stickstoffdüngung hatte bei den Rettichen keine signifikante Wirkung auf die Anzahl Blätter pro Pflanze. Bei der Behandlung mit 200 kg N/ha waren der Durchmesser, die Länge, das Gewicht und der Ertrag am höchsten. Gleichzeitig wurde festgestellt, dass der Gesamt-Stickstoff- und Nitratgehalt sich mit steigender Stickstoffgabe ebenfalls erhöhten. Aus diesem Grund sollte die übliche Stickstoffdosis bei Rettichen beibehalten werden, um gute Erträge eines gesunden Produkts zu erhalten

Introduction

Radish (*Raphanus sativus* L.) is an important vegetable crop grown extensively in Turkey. Recently, excessive amounts of fertilizers have been used on many soils for commercial vegetable production in Turkey. Nitrogen is usually more important element for increasing plant growth than any other nutrients (PECK and MACDONALD 1984). Nitrogen fertilization may affect the vegetative growth of plant and nitrate accumulation (PECK et al. 1989). Radish is nitrate accumulating vegetable crop (ALCICEK and BASLAR 1995). Since the reduction products of the nitrate might be toxic for humans, research has been carried out on the prospects to produce radish cultivars with low nitrate contents (NIEUWHOF and JANSEN 1993). One of the most important factors in nitrate accumulation in plants was soil nitrogen (KARACAL and TÜRETKEN 1992; AYDIN and AKTAS 1995; PECHOVA et al. 1999).

The efficiency with which plants absorb and metabolise NO_3 or NH_4 varies with environmental conditions and plant species (BARKER et al. 1983). Numerous studies have shown that the highest growth of plant in radish was recorded with the highest rates of N (JOSHI and CHAUHAN 1985; SRINIVAS and NAIK 1990). On the other hand, nitrogen content of plant parts increased by increasing nitrogen doses (KARAÇAL and TÜRETKEN 1992; AYDIN and AKTAS 1995). Some researcher noted that at low nitrogen levels of the soil genetic differences might be masked by accidental variation (NIEUWHOF and JANSEN 1993)

The objective of this research was to determine the effects of usual and excess nitrogen fertilization doses on growth, yield and nitrogen content of five different radish (*Raphanus sativus* L.) genotypes commonly grown in Turkey.

Material and Methods

This study was conducted under field conditions at Agricultural Faculty of Ataturk University Turkey in 1996 and 1997, with five different radish (*Raphanus sativus* L.) genotypes commonly grown by Turkish farmers (ANON. 1996). These genotypes consisted of (1) 'Fındık', (2) 'Kestane', (3) 'Bayır', (4) '8 TR-18' and (5) 'Antep'. The soil of the experimental area was of loamy texture with neutral pH. The experimental soil had 1.1–1.3 % organic matter, 36.0–38.4 kg/ha N, 41.4–45.3 kg/ha P_2O_5 and 1100–1240 kg/ha K_2O in 1996 and 1997 respectively.

The experimental design combined a randomised complete blocks with 3 replications. The N rates tested were N_0: 0, N_1: 100 and N_2: 200 kg/ha as ammonium nitrate (NH_4NO_3). N_1 dose was accepted as usual (normal) dose according to the previous reports (GÜNAY 1984; GÜVENC 1996). In low N doses, no significant difference among the genotypes was determined in term of nitrate accumulation (NIEUWHOF and JANSEN 1993). Therefore, N_2 was applied as excessive N dose in

this research. Additionally, all plots received 80 kg P_2O_5/ha (GÜNAY 1984) as triple super phosphate. All of the P_2O_5 and half of the NH_4NO_3 fertilizers were broadcasted uniformly prior to planting onto the soil surface by hand and incorporated. The remaining half of nitrogen was given 20 days after the planting (SRINIVAS and NAIK 1990). Seeds were sown on July 27 in 1996 and July 25 in 1997. The plants were thinned after emergence to maintained at an inter and intra row spacing of 20 cm (GÜNAY 1984) with a plot size of 2.1 x 1.2 m. During the development phases, all of the plant care practices have been irrespectively applied on the plants in each plot.

The number of leaves per plant, weight, diameter and length of root, total nitrogen and nitrate content of root and the yield were determined. All of the observations except yield were made on randomly selected 40 plants. The total N content were determined according to Kjehldal procedure and nitrate analyses with Phenol disulphonic acid method (KACAR 1972). Data were subjected to ANOVA and the differences between means were tested according to LSD.

Table 1. Effects of nitrogen fertilization on growth in radishes.
Wirkung der Stickstoffdüngung auf das Wachstum von Rettich.

N (kg/ha)	'Fındık'	'Kestane'	'Bayır'	'8 TR-18'	'Antep'
			Number of leaf per plant		
			1996		
0	7,93 NS	8,23NS	9,06 NS	11,02NS	10,40 NS
100	10,23	8,83	9,63	13,14	12,05
200	9,06	9,03	10,83	13,00	12,76
			1997		
0	8,01 NS	9,00 NS	10,00 NS	10,83NS	9,87 NS
100	9,53	9,34	10,62	12,77	11,87
200	9,40	9,37	10,91	13,28	12,06
			Root weight (g)		
			1996		
0	137,33c*	220,00c*	213,31b**	225,56c**	376,66b**
100	167,35b	321,42b	251,60a	295,67b	456,61a
200	196,33a	385,22a	273,36a	333.47a	498,38a
			1997		
0	143,14c**	263,78c*	220,15c*	261,25c*	344,01c*
100	176,78b	337,14b	270,72b	320,44b	403,84b
200	191,46a	354,35a	304,11a	350,55a	440,23a
			Root diameter (cm)		
			1996		
0	5,75b**	8,01c*	6,53b**	5,71b*	7,77 b**
100	5,95b	9,58b	7,41a	6,58ab	8,26a
200	6,60a	11,20a	7,58a	7,16a	8,53a
			1997		
0	5,81b**	8,60c*	7,00b*	6,21c**	7,60b*
100	6,26a	9,78b	7,97a	7,14b	8,46a
200	6,40a	10,91a	8,04a	7,67a	8,69a
			Root length (cm)		
			1996		
0	8,06 NS	7,9c*	5,08b*	18,83b*	13,93c*
100	8,08	9,1b	6,38a	21,76a	16,33b
200	8,25	10,6a	7,00a	21,83a	18,15a
			1997		
0	8,31 NS	8,37c**	5,38c*	20,08b**	13,50c*
100	8,84	9,56b	6,83b	22,88a	15,00b
200	8,99	10,50a	7,49a	22,95a	16,63a

(*): Significant at the $P<0.01$ levels.
(**): Significant at the $P<0.05$ levels.
(NS): Non significant at the $P=0.05$

Results

Number of leaves per plant

The results obtained from different doses of nitrogen treatment on the number of leaves per plant showed no differences for both years. However, the application of 200 kg N/ha gave a slight increase in terms of leaf number per plant (Table 1).

Root growth

In this study, maximal root growth was obtained with N_3 doses. The root weight of radishes was significantly higher in the treatment of both nitrogen doses when compared to the control group (Table 1). The root weight was the highest in 200 kg N/ha treatment and the lowest in the control treatment. Diameter and length of roots showed similar trend as was the case for root weight. The highest root diameter and length in five radish genotypes were obtained from 200 kg N/ha application.

Root yield

There were statistically significant differences among the N doses on the root yield in radish in both experimental years. The highest root yields were recorded at the 200 kg N/ha application followed by 100 kg N/ha and control treatments for both cultivars and years (Table 2).

Nitrogen content

Total nitrogen content of root in five radish genotypes increased with higher nitrogen applications in both years (Figure 1). The total N absorbed by root was positively related to amount of nitrogen applied. On the other hand, nitrogen application significantly increased nitrate accumulation in genotypes (Figure 2).

Discussion

Responses of the radish plants to nitrogen fertilizers were consistent in both years. Present results indicated that there were no significant differences among N

Table 2. Effects of Nitrogen fertilization on root yield of radishes.
Wirkung der Stickstoffdüngung auf den Ertrag von Rettich.

N (kg/ha)	'Fındık'	'Kestane'	'Bayır'	'8 TR-18'	'Antep'
			Root yield (kg/plot)		
			1996		
0	5,49c*	8,77c*	8,53b*	9,02c**	17,06b*
100	6,69b	12,84b	9,90a	11,82b	20,26a
200	7,84a	15,40a	10,93a	13,33a	22,04a
			1997		
0	6,23b**	10,52c*	9,00c**	9,90c*	13,80b*
100	7,17a	13,48b	10,60b	12,62b	16,84a
200	7,46a	14,16a	11,58a	13,57a	17,60a

(*): Significant at the $P<0.01$ levels. (**): Significant at the $P<0.05$ levels.

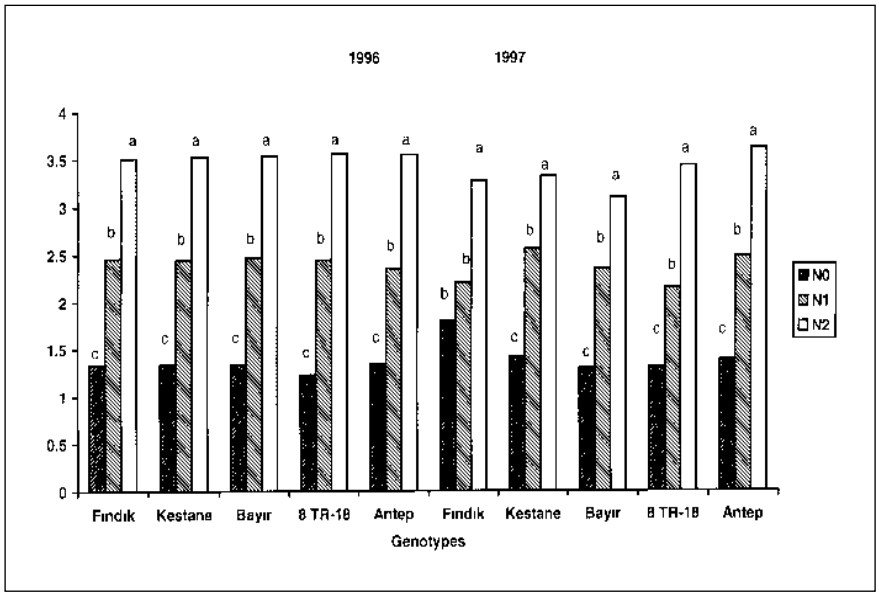


Figure 1. Effect of nitrogen fertilization on total nitrogen content (%) in radishes. Different letters in a column are significantly different ($P<0.05$). *Einfluss der Stichstoffdüngung auf den Gesamt-Stickstoffgehalt (%) in Rettich. Abweichende Buchstaben in den Spalten weisen auf signifikante Unterschiede hin ($P<0.05$).*

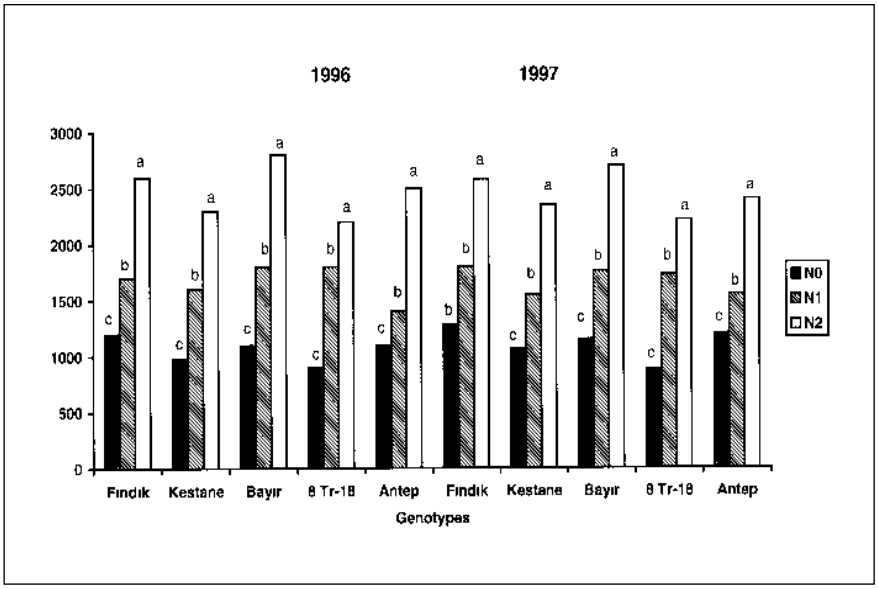


Figure 2. Effect of nitrogen fertilization on nitrate accumulation (ppm) in radish. Different letters in a column are significantly different ($P<0.05$). *Einfluss der Stichstoffdüngung auf die Stickstoffanreicherung in Rettich. Abweichende Buchstaben in den Spalten weisen auf signifikante Unterschiede hin ($P<0.05$).*

doses in terms of the number of leaves per plant. However, N application strongly increased root growth, root yield and nitrate accumulation in both years. Other studies noted that nitrogen fertilization could affect vegetative growth such as root growth (HORST et al. 1985; PECK et al. 1989; GUVENC 1995; PARTHASARATHI et al. 1999), and high N rates usually increased plant size (MULLINS 1987).

Hence numerous studies have shown that the highest growth of plants in radish was recorded at the highest N rates (JOSHI and CHAUHAN 1985; SRINIVAS and NAIK 1990). Present results obtained in this study in terms of root size of radish supported by the results of previous studies (JOSHI and CHAUHAN 1985; SRINIVAS and NAIK 1990). On the other hand BARKER et al. (1983) reported that root growth of radish was generally reduced with decreasing N level, which is again in agreement with the results of present study. In this study, root yield was increased with increasing rates of N, and the highest yield was recorded at the highest N rate (Table 2). Similar results have also been reported in some radishes (JOSHI and CHAUHAN 1985; SRINIVAS and NAIK 1990) stating that root yield of radish was increased with increase in the amount of nitrogen.

In this research, nitrogen content of the radish roots was significantly affected by nitrogen fertilization. There was a much greater increase in nitrate N as well as total nitrogen in the root parts. Furthermore, the data from this study strongly indicated that nitrogen fertilization was more responsive for nitrate accumulation of root on radish genotypes. In this experiment, due to the similar reaction of all radish genotypes to the supply of nitrogen was the most important factor determining total nitrogen and nitrate content of the roots. These results are also consistent with the findings of some other researcher (KARACAL and TÜRETKEN 1992; NIEUWHOF and JANSEN 1993; MALAKOUTI et al. 1998).

In conclusion, the results of this study suggest that the radish genotypes tested had increased the growth characteristics with the increasing N doses. But this was not very acceptable outcome in term of the nitrate accumulation, which is harmful for human health. Therefore, the normal nitrogen doses should be applied in these radishes to have better yield and healthy crops for human nutrition.

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