INTERCROPPING LEEK WITH CELERY; EFFECTS ON YIELD, NITROGEN UPTAKE AND ROOT DYNAMICS

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PREFACE

Het resultaat van vijf maanden onderzoek naar mengteelten van prei en selderij aan het Zwitserse Forschungsanstalt für Obst- Wein- und Gartenbau in Wädenswil ligt nu in afgeronde vorm voor mij. Wat rest is deze bladzij gereserveerd voor de mensen, zonder wie dit werk onmogelijk was geweest.

Als eerste wil ik familieleden en vrienden bedanken die mij in Zwitserland gesteund hebben door kaarten, brieven, e-mails en zelfs bezoeken. In het bijzonder wil ik mijn ouders noemen, die altijd voor mij klaar staan, belangstelling tonen voor mijn werk en zelfs niet te beroerd waren in hun vakantie een dagje in mijn preiveld te wieden. Verder Pakeza, met wie ik het huis in Wädenswil gedeeld heb. Zonder elkaar had ons leven in Zwitserland een stuk inspiratie gemist. Daniël en Gabriëla bedankt voor jullie pogingen mij in Zwitserland ver van huis toch thuis te laten voelen. Verder wil ik al die mensen bedanken die op één of andere manier iets voor mij betekend hebben, in de tijd in Zwitserland, maar ook daarna, en die ik hier niet genoemd heb. Zonder jullie steun had ik 'het Zwitserlevengevoel' minder positief ervaren.

Natuurlijk zijn er ook mensen zonder wie dit project er nooit geweest was. Daniël Baumann wil ik bedanken voor de begeleiding van het praktische deel van mijn experimenten in Zwitserland en Lammert Bastiaans wil ik bedanken voor de begeleiding van de verslaglegging. Dat een mens niet alles alleen kan is mij duidelijk geworden; Ernst Barben (ook bedankt voor het bergbeklimmen), Benni, Ursina, Blanca en de mensen van Sandhof, zonder jullie hulp was het werk voor mij alleen zeker teveel geweest.

Nooit gedacht dat ik mij zo lang bezig heb gehouden met eten wat ik eigelijk helemaal niet lekker vind, namelijk selderij. Of het in combinatie met prei enige smaakverbetering oplevert, laat ik graag aan andere experts over...

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SUMMARY

In field vegetable production, cultivation of leek is accompanied by intensive use of pesticides. Since leek is an open crop, weed control is one of the major problems. Also leek is very susceptible to pest infestations and diseases as thrips, leekmoth and leek rust. Experiments with subterranean clover however showed that crop yield reduced drastically as a consequence of plant competition. Intercropping leek with celery has proven to reduce insect infestations and would increase soil cover, which could reduce the amount of chemicals needed for cultivation of leek. The aim of this research project was to 1) to study yield formation and nitrogen uptake of leek and celery in an intercropping system 2) to study the rooting systems of leek and celery in intercrop and monocultures and relate these findings to yield formation and nitrogen uptake.
In a field experiment the effect of intercropping on yield, quality and root development was investigated at various nitrogen application rates, whereas in an additional rhizotron experiment the effect of intercropping on root development was investigated. These experiments showed, that, at every nitrogen level, intercropping with celery reduced yield, nitrogen uptake and quality of leek considerably, as a result of competition for light and nutrients. However, yield and nitrogen uptake of celery in intercrop were higher than in monoculture.
Factors affecting the competitive abilities of leek and celery are the differences of the crops in growth rate, morphology, development of the root system and efficiencies in using nitrogen and light. At each nitrogen application rate, these factors were affecting each other in a different way, but with the same outcome; leek was out competed by celery. Improvements of this intercropping system should be aimed at equalising competition between leek and celery, while maintaining the advantages of intercropping. Options for improving the intercropping system of leek and celery are discussed.

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1. INTRODUCTION

Recently a lot of attention has been paid to the reduction of the use of pesticides in agriculture. Farmers often use artificial fertilizers and pesticides, as an insurance for a good yield and a good crop quality. This practice increases emissions to the environment and in this way causes risks for public health and flora and fauna. Control of the use of agrochemicals resulted in stricter environmental legislature; e.g. the Multi Year Crop Protection Plan in the Netherlands. The aims of this plan are to reduce the dependance of farmers on chemical crop protection, to reduce the emissions to the environment and to reduce the extent of the use of pesticides. Considering herbicides, the targets are: a reduction of 55% of the current use (reference 1984-1988) by 2010. In field vegetable production, a reduction of 38% is set (Ministerie van Landbouw, Natuurbeheer en Visserij, 1990). The aim of a reduction of pesticide use in agriculture can also be found in the attention paid to alternative production methods as Integrated Production and Ecological Farming. In Switzerland the demand of consumers for ecological products is still rising (Gysi *et al.*,1996). About 5.6 % of the land used in agriculture is in use for ecological production. In the Netherlands the area in use for ecological production is 0.7 % of the total area for agricultural production (CBS, 1997).

In field vegetable production alternatives for the use of pesticides can be found in cultural measures and mechanical weed control. For example in practice, a crop rotation with alternating weak and strong competitive crops and the use of green manure are used to prevent development of weed populations. One cultural measure that recently got a lot of attention is intercropping of vegetable crops. Intercropping is the cultivation of two or more crop species in such a way that they interact agronomically (biologically) (Vandermeer, 1989). It is a cropping system that has a long history and is widely used in tropical regions.

Intercropping offers potential solutions for weed- and pestcontrol and can additionally prevent the soil from erosion, leaching, soil compaction and solarization.

Leek is an economically important crop. It is a crop with a low competitive ability and therefore weed control is a major problem. Leek is also very susceptible to pest infestations. Intercropping leek with subterranean clover (*Trifolium subterraneum* L.) drastically reduced thrips (*Thrips tabaci* Lindeman) infestations and slightly surpressed leek rust (*Puccinia allii*). Although the quality of leek improved, crop yield reduced considerably as a result of plant competition (Theunissen and Schelling, 1996). Also, clover is a crop without direct economic importance. Therefore it is preferrable to use an intercrop that is marketable. Experiments showed that intercropping leek and celery reduced thrips infestations in leek up to 40%, as compared to the monocrop (Dobolyi, Städler & Baumann, 1996). Celery as a component-crop of the intercrop seems an attractive alternative in practice because leek and celery are both marketable vegetables, have the same growing period, require about the same amount of nutrients and are harvestable with the same machine.
Celery is also attractive because it is more competitive against weeds than leek; due to rapid growth and development of many leaves it covers the soil faster than leek.

Intercropping offers advantages, but growing two or more crops together might cause competition between the crops for light, water and nutrients. This can lead to yield or quality loss of one or even both crops.
Roots supply water and nutrients to the plant and in this way influence growth. The ability of roots to take up water and nutrients from the soil is related to the amount of roots within the soil, the specific activity of the roots (rate of uptake per unit root length) and the distribution of roots (spatial partitioning of roots within a soil volume) within the soil (Berntson & Woodward, 1992). These variables differ for each crop. Hence, if competition for nutrients occurs in the intercrop of leek and celery, the rooting system might give one of the crops a competitive advantage over the other crop.

On the other hand it is also possible that an intercrop uses the nutrients more efficiently than the monocultures of the crops. This can occur when species for example differ in their growth patterns, so that the crops have their major demands at a different time (Willey, 1979). Also a mixture of two species differing in rooting depth can be beneficial as the deep rooting species can draw on an extra supply of nutrients present in the deeper soil layer. In this case the crops can even yield more than in monoculture (Spitters and references therein, 1980).

Competition is also related to the amount of nutrients available. One crop might outcompete the other at a high nitrogen regime, but when nitrogen supply is insufficient, the other crop might be the strongest competitor.

The objective of this study was: 1) to study yield formation and nitrogen uptake of leek and celery in an intercropping system 2) to study the rooting systems of leek and celery in intercrop and monocultures and relate these findings to yield formation and nitrogen uptake.

2. INTERCROP COMPONENTS

2.1 Leek

Leek (*Allium porrum* L.) is a member of the large family of *Alliacea*. Within the genus *Allium*, there are more than 500 species. The characteristic odor and taste of the *Allium* species is their best known feature. The genus *Allium* is widely distributed over the warm-temperate, temperate and boreal zones of the northern hemisphere. Leek belongs to the species *A. ampeloprasum* L. which includes for example also great headed garlic.
Leek is a biannual plant, which develops leaves during the first (vegetative) year. Flower stalks do mostly not develop until the second (reproductive) year. Cultivated leek will be harvested in the vegetative stage. Different types of leek excist and these cultivars differ in the length and slenderness of the stem, leaf colour, winter hardiness and tendency for bulbiness (Brewster, 1994).
Leek is an economically important crop. Weed control is one of the major problems in the production of leek. Allium crops are very susceptible to early-season weed competition, due to their morphology (upright, narrow leaves) and slow relative growth rate (Rubin, 1990). Also the allium crop is shallow rooted and has a low root density. As a result weeds can establish easily in the crop (Brewster, 1994). Control of weeds is basically accomplished chemically or mechanically, by inter-row hoeing and within-row hand weeding.
Leek is also very susceptible to insect- and pestinfestations. The insects thrips (*Thrips tabaci*) and leek moth (*Acrolepiopsis assectella*), the fungus *Puccinia allii*, causal agent of leek rust, and leaf spot diseases (*Phytophtora porri, Alternaria porri, Cladosporium allii-porri*) are the main problems in leek cultivation (Bokhorst *et al.*, 1992).

Roots of leek vary between 0.5 and 2 mm in thickness and are very sparcely branched with

one or two lateral branches per centimetre of primary root. Lateral branches rarely rebranch. As a result, the root length per unit volume of soil under leek is low compared with other species (Brewster, 1994). This has consequences for nutrient uptake; the total annual amount of nitrogen taken up by leek is 140 kg N/ha. In practise, the adviced nitrogen application is 200-250 kg N/ha however. The loss of nitrogen is higher than in other crops, which is caused by the fact that leek does not root well (Bokhorst *et al.*, 1992).
Allium roots are readily colonised by mycorrhizal fungi and these have been shown to enhance nutrient absorption, particularly under conditions of nutrient scarcity, in essence by increasing the absorbing surface area of the root system (Brewster, 1994).

2.2 Celery

Celery (*Apium graveolens* L.) is a member of the family of *Umbelliferea*. Celery was already cultivated by the Egyptians, Romans and Greeks and the wild variety of the crop is distributed over Europe and the north coast of Africa. Celery is a biannual plant with a vegetative phase in the first year and a reproductive phase in the second year. In the vegetative phase a rosette of leaves and stems is formed. After a period of cold the plant will flower and develop seed. Celery will be harvested in the vegetative stage. Celery has a better competitive ability against weeds than leek, because it is developing a foliage of many leaves that rapidly covers the soil.

Celery is affected by few pests or diseases. The main problem is a leaf spot disease, which is caused by the fungus *Septoria apiicola*. Plants are very susceptible to infection when the weather is warm and moist (van Wijk, 1994).

Celery forms many side roots that grow in the same direction as the main roots. The main part of the roots is present in the upper 20 cm of the soil. Celery can root very deep though; at 80 cm roots can still be found (van Wijk, 1994).

3. MATERIALS AND METHODS

Planting material:

In all experiments leek (*Allium porrum*) cv. Zefa Plus and celery (*Apium graveolens* L.var.dulce) cv. Ramon was used.

3.1 Experiment 1: The effect of intercropping on yield, quality and root development at various nitrogen levels

3.1.1 Experimental layout

The effect of intercropping on crop growth and root development at various levels of nitrogen supply was examined in this trial. For this purpose a field experiment was conducted during the period of June 3 till September 4. The experiment was laid out as a completely randomised block design in four replications. Each replicate consisted of nine treatments; all possible combinations of three cropping systems and three nitrogen levels (table 3.1).

Cropping system		Nitrogen level	
L :	Leek grown in monocrop	N_0 :	no fertilizer-N application
C :	Celery grown in monocrop	N_1 :	low N application rate (50 kg N/ha)
LC :	Leek and celery grown in intercrop	N_2 :	N-application rate as in practice (200 kg N/ha)

Table 3.1 Cropping systems and nitrogen levels in the field experiment

Leek and celery were planted on June 3 and 4, respectively. The plants were planted in beds of 1.2 m wide with a plot length of 2.5 m. In between the beds was a path of 0.30 m. Each bed consisted of four rows with a row spacing of 0.30 m. The within row planting distance for leek and celery was 0.15 m and 0.30 m, respectively. This resulted in a planting density for leek in monocrop of 18 plants/m^2, for celery in monocrop of 9 plants/m^2 and for the intercrop of 13.5 plants/m^2. In the experiment a replacement design was used which meant that in the intercrop every second row of leek was replaced by a row of celery. The plants in intercrop were planted in the same density as in the monocultures. Planting of leek was done by means of a planting machine. Planting of celery was done manually.

Nitrogen fertiliser was applied as calcium ammonium nitrate. To study plant-plant interaction in a situation of limited supply, the first treatment consisted of no application of nitrogen. To examine the effects of a low dosage of nitrogen, 50 kg of nitrogen was applied per hectare. It was estimated that this dosage would cover about 80 % of the demand of leek (R. Booij, personal communication). The highest application rate (200 kg/ha) was used to avoid competition for nitrogen by supplying this resource in ample supply.

On June 1 Superphosphate was applied at a rate of 155 kg P/ha. K_2O was applied at a rate of around 190 kg/ha. Additional fertilization took place at July 10 and August 5 when K_2O was applied at a rate of around 112 kg/ha.

The experiment was irrigated at expert's indication. In appendix 1 total precipitation and average temperature during the growing season is presented.

Weeding was done manually. On July 10 a pesticide treatment against thrips and leekmoth took place. Marshal (0.25 %) and Dithane (0.2 %) were applied at a rate of 10 l/ha. On August 7 an additional treatment with Marshall took place at the same rate.

The experiment was carried out on a sandy loam soil. The soil contained large stones and at various places an unpenetrable layer was present at a depth of about 50 cm. The previous crop, rubarb, was cultivated on the experimental field in the spring of 1996. After harvest of rubarb, grass was grown on the field. The experimental field had a slope of 2.9 %. Block IV was on top of the slope and block I was at the lowest side of the slope (appendix 2).

3.1.2 Plant- and soil analysis and observations

Two treatments (N_0 and N_2) were harvested three times; at July 7 (34 days after planting (DAP)), August 4 (62 DAP) and September 9 (92 DAP). Treatment N_1 was harvested only once; at September 9 (92 DAP).

Nondestructive observations

Every two weeks, the diameter and SPAD-value of 5 marked leek plants per treatment were registered. For celery only SPAD was determined. Diameter was measured by means of a digital calliper rule (Mitotuyo; Digimatic). For every marked plant, diameter was measured at about 5 cm above soil level. Two measurements were taken to obtain maximum and minimum diameter (D_{max} and D_{min}). These diameters were used to calculate the stem area (A);

$$A = \pi * \frac{1}{2} D_{max} * \frac{1}{2} D_{min}$$

SPAD of the leaves was determined using a handheld chlorophyll meter (MINOLTA; SPAD-502). From every marked plant, five measurements were taken of different leaves, and their readings were averaged. Measurements were taken from undamaged leaves that were on the sunside of the plant. Light interception of the canopy was also measured every two weeks. A lightmeter (Sunfleck Ceptometer) with a length of 30 cm was positioned transversally to the crop rows. Five readings per treatment per replication were averaged to obtain the radiation level above the canopy and 5 readings were averaged to obtain the light interception under the canopy.

Plant analysis

At each harvest, 6 plants were sampled per plot. For leek, stem height and stem diameter were measured and SPAD was determined. Plants were divided into leaf and stem. Fresh weight (FW) of these organs was determined. For celery, SPAD and FW of the total plant was determined. Leaf area was determined by means of a LI-3100 Area Metre (LI-COR inc. Lincoln, Nebraska). Dry matter (DM) of all plant organs was determined after drying for 24 hours at 70 C°. Of the dried plants a subsample was taken for analysis of total nitrogen. Dried plant samples were kept in paper bags in a cool, dark and dry place until the moment of analysis. Before analysis the samples were shortly dried, grinded and sieved.

To compare the production of the monocultures with the intercrop, replacement diagrams were used. In a replacement diagram the relative yields (RY's) of each species are plotted against density. Relative yield is expressed as the ratio between absolute yield of the species in intercrop and the absolute yield in monoculture. These RY values were used in two ways;

- As a measure of the total productivity of the intercrop. If the total of the RY's of leek and celery (RYT) > 1, the yield in intercrop is higher than in monocrop. If the RYT > 1, compensation or mutual cooperation occurs. Compensation is the situation where one crop yields less than expected and the other more. The term mutual cooperation is used when the yield of each species in the intercrop is greater than expected on its performance in monoculture. Expected yield is the yield that would be obtained if the species experienced the same degree of competition in intercrop as in monoculture. If the RYT < 1, inhibition takes place. Mutual inhibition is the situation where the actual yield of each crop is less than expected. The commonest situation though is the situation of compensation (Willey, 1979).
- As a measure of competition between the crops. If the yield in intercrop is higher than 50 % of the yield in monoculture, the intraspecific competition is higher than the interspecific competition. Another measure for crop competitive ability is the relative crowding coefficient (k). It is a measure of whether a species has produced more or less yield than expected.

$k = (1 - p) / ((w_{io} - w_i) - p)$
$p = d_i / d_{io}$ ***(density in intercrop versus density in monoculture)***
w_{io} = ***individual plant weight in monoculture*** w_i = ***individual plant weight in intercrop***

If a species has a coefficient less than, equal to, or greater than one it means that it has produced less yield, the same yield or more yield than expected, respectively (Willey, 1979).

Analysis of total nitrogen took place by means of a gasflow infrared detector (LECO). About 0.50 g of plant material was weighed and put in tin foil cups. These samples were analysed in the detector. After analysis of total nitrogen uptake, the following efficiencies were calculated of the crops in intercrop and monoculture (Janssen, 1996).

Agronomic efficiency	:	$(Y_{Nx} - Y_{N0}) / N_{fert(x)}$
Recovery fraction	:	$(N_{uptake\ Nx} - N_{uptake\ N0}) / N_{fert(x)}$
Utilisation efficiency	:	$(Y_{Nx} - Y_{N0}) / (N_{uptake\ Nx} - N_{uptake\ N0})$
Y_{nx}	=	Yield (kg/ha) at nitrogen application rate x
$N_{uptake\ Nx}$	=	Nitrogen uptake (kg/ha) at nitrogen application rate x
$N_{fert(x)}$	=	Nitrogen application rate of x kg/ha

Root analysis

At the first and second harvest soil samples were taken for root analysis. Samples were taken with an electric soil core sampler with a diameter of 5.0 cm. Samples were taken in the plots of the N_0 treatment only, at a depth of 0-0.30 m and 0.30-0.55 m. Sampling position was related to the position of the plant. In monocrop, two samples were taken per plant; one right next to the stem of the plant and the other in the middle between the rows at a distance of 0.15 m. In intercrop, three samples were taken; one right next to the stem of celery, one right next to the stem of leek and one in the middle between the rows at a distance of 0.15 m (figure 3.1).

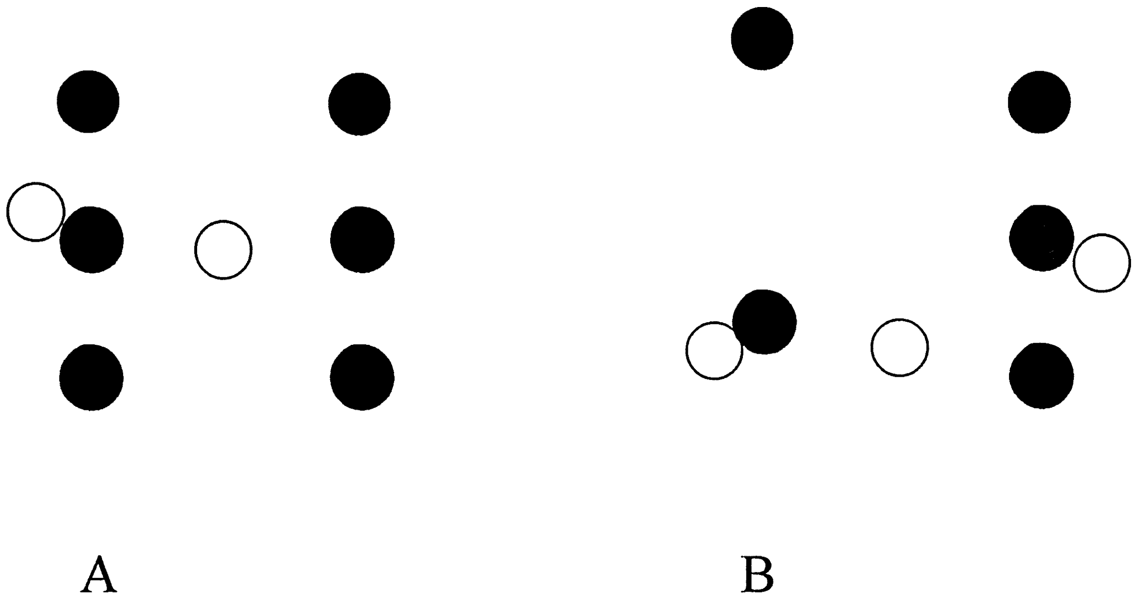


Figure 3.1 Sampling positions of root samples (○) in monoculture (A) and intercrop (B). ● represents position of plants in the row

Washing procedure

After sampling, samples were deep frozen to facilitate separation of roots from the soil (Böhm, 1979, Williams and Baker, 1957). Frozen samples were cut and divided into sub samples at a depth of 0.15-0.30 m and 0.30-0.45 m. These sub samples were first washed over a 2.0 mm sieve and afterwards over a 1.0 mm sieve to separate roots from soil particles. From each sieve, roots were removed by means of sprinklers and collected in a plastic buckets. The two buckets, containing roots and water were finally sieved over one 0.5 mm sieve, which in the end contained all the roots recovered from the soil.

Root length was determined using the line intersect method (expt. 2; Ch 3.2.2). In this case, the 0.5 mm sieve was placed in a petridish with water. Roots were counted on a grid of 1.50 by 1.50 cm. Roots were counted, following the procedures described in chapter 3.2.2.

Soil analysis

Before planting and at final harvest, soil samples were taken at a depth of 0-0.30 and 0.30-0.60 m for determination of total nitrogen content. Per treatment, 5 soil samples were taken of each replication. Samples were taken with single gouge augers which were driven into the soil with a mallet. Samples were deep frozen until the moment of analysis.

Prior to analysis of total nitrogen content, samples were sieved through a 10 mm sieve and dried at 60 C° for 24 hours. About 1.00 g of soil was weighed and put in a tin foil cup and analysed for total nitrogen with a gas flow infrared detector (LECO).

3.2 Experiment 2: The effect of intercropping on root development in rhizotrons

3.2.1 Experimental set up

A rhizotron experiment was carried out to study the effect of intercropping on root development of leek and celery. This experiment was conducted during the period of June 5 till September 10.

The rhizotron observation boxes had a depth and length of 1.0 m and were 7.3 cm wide at the top and 5.5 cm at the bottom (fig. 3.2). The distance between two individual observation boxes was 0.30 m. The observation boxes were put on the rails of a rack. From these rails the boxes could be rolled on a wagon where observations could be made. Both sides of the observation boxes had a glass panel which was covered to avoid daylight and prevent growth of algae. The experiment was protected by a hailnet, which reduced the incoming photosynthetically active radiation with about 19%. During the experiment the water content of the soil was monitored by means of tensiometers placed at a depth of 0.8, 0.6 and 0.4 m. The boxes were watered on hot days when it did not rain by means of a sprinkler. Weeding was done by hand. Soil temperature in the boxes was measured on 9 September from 11.00 until 17.00 hr. at depths of 3.5, 20 and 50 cm. Temperature at a depth of 20 and 50 cm varied between 18 and 23 C° during the day. Temperature at 3.5 cm depth was around 5 C° higher than at 20 and 50 cm depth. Air temperature on this day varied between 21 and 28 C°.

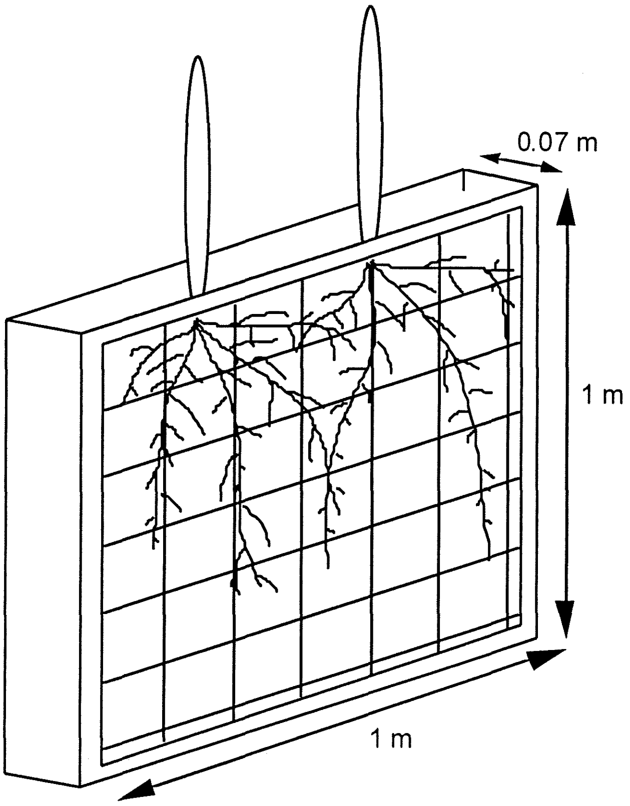


Figure 3.2 Rhizotron observation box

On May 21 the observation boxes were filled with soil from Sandhof, the site on which the field trial (expt. 1) was laid out. Before filling, the soil was sieved through a 2 cm sieve, to avoid large particles and to diminish variation in compaction between individual observation boxes. In total about 73 kg soil was used to fill each box, resulting in a bulk density of about 1.6 kg/m^3, comparable to the density in the experimental field. During filling of the boxes the soil was slightly stirred and pressed together with a stick. The experiment consisted of a total of three treatments in six replications (table 3.2).

L	:	Leek in monocrop
C	:	Celery in monocrop
LC	:	Leek and celery in intercrop

Table 3.2 Cropping systems in the rhizotron experiment

Planting was done on June 5. The plants were planted at a distance of 0.25 m (resembling row distance), which resulted in four plants per box. The experiment resembled the N_0-level in experiment 1 and received a gift of 1.5 g N/box on June 30. This is equivalent to 50 kg N/ha. Fertilizer was applied as water soluble fertilizer (Flory 1, N:P:K ratio 4:1:2). Fertilizer was applied, because the soil volume in the boxes was limited and no additional nitrogen was released by mineralisation as in the field experiment. Also nitrogen could easily leach from the boxes due to rain and irrigation. Fertilisation level was equal to the nitrogen content (N_{min}) in the N_0-level in the field experiment.

3.2.2 Observations and analysis

Non destructive observations

Root development was recorded every ten days, according to the line intersect method described by Tennant (1975) and Böhm (1979):

Comparisons of intersection data with the measured actual root length showed a linear relation between the number of intersections and the actual root length (Böhm and references there in, 1979). A grid system of 5 by 5 cm was placed in front of the observation window and every root in this plane crossing a grid line system was recorded. Counts of one were given to a root crossing a line, a root end touching a line and a curved portion touching a line. Counts of two were recorded for roots laying along a grid line. Number of intersections (N) was converted to root length (R) using the equation (Tennant, 1975):

Root length (cm) = 11/14 x Number of intersections x Grid Unit (cm)

Root growth was recorded in between the two plants in the middle of the box on both sides of the observation panels. Recording area was 25 cm wide (5 grid squares) and varied in depth depending on depth of root growth. At every growth recording day the diameter of leek was measured and SPAD was determined for both leek and celery.

Root and shoot harvest

On August 12-15, nine boxes (three treatments x three replications) were harvested and root and shoot dry weight was determined. This harvest was taken because the roots of most of the leek plants had reached the bottom of the observation boxes. This would cause an error in further observation through counting and it would be difficult to harvest and separate the rooting systems of the plants at a later date if they were left to grow. At harvest, one of the glass panels was broken and roots were carefully washed out by means of a sprinkler. The root systems of the plants were separated in water. Afterwards, the entire, intact plant was put on the remaining glass panel of the observation box. This panel was floating in water in a large tank. Because the roots were in the water on the panel they could easily be counted and from every plant the number of main roots was determined at a depth of 0, 0.30, 0.60 and 0.90 m.

SPAD and diameter were measured for leek and SPAD for celery. Leek was separated into leaf and stem. Shoot and root dry weight were determined and plant parts were analysed for total nitrogen content according to the procedures described in chapter 3.1.2.

Final harvest took place on September 10, when from the remaining nine boxes the plants (just shoots) were harvested. For leek, SPAD and diameter was determined and plants were separated into leaf and stem for determination of FW and DM. For celery SPAD, FW and DM was determined. Plants were analysed for total nitrogen as described in chapter. 3.2.1.

3.3 Statistical analysis

All data were tested for homogeneity of variance and ANOVA was performed. The significance of difference was assessed with an LSD-test ($p = 0.05$).

4. RESULTS

4.1 Experiment 1

As mentioned in chapter 3.1. periodic harvests of leek, celery and intercrop grown at nitrogen application rates of 0 and 200 kg N/ha were taken at 34, 62 and 92 days after planting (DAP). In this chapter, these two application rates will be referred to as non fertilised (0 kg N/ha) and fertilised (200 kg N/ha) treatments. For the nitrogen application rate of 50 kg N/ha only one harvest was conducted (92 DAP).
Based on the observations, the interpolated time course of the various characteristics will be presented in the next sections. In the first two sections, performance of leek and celery in monoculture will be characterised both on an area basis (production and nitrogen uptake per ha) as on an individual plant basis (growth and nitrogen uptake per plant). In the next two sections a comparison will be made between growth and nitrogen uptake of leek and celery in intercrop and monoculture. For this comparison, data were expressed on a per plant basis since density of each crop in intercrop was only half of that in monocultures. Finally, the production and nitrogen uptake of the intercrop will be compared with the production and nitrogen uptake of the monocultures of leek and celery.

4.1.1 Characterisation of growth of leek in monocultures

The time course of dry matter production of leek expressed in g/plant and in ton/ha is given in figure 4.1 A. At final harvest, clear differences were observed between the different nitrogen levels. Biomass production was highest for the fertilised and lowest for the non fertilised treatment. Dry matter production of leek at an application rate of 50 kg/ha was found in between these treatments and differed significantly from both. Differences in biomass production were not apparent at all stages of growth; initially, growth rate of leek was small and biomass production of leek was not affected by nitrogen application rate. At 62 and 92 DAP a significant difference between non fertilised and fertilised leek was observed.

A similar trend was found for leaf area development (figure 4.1 B); initially leaf area development was slow, but from day 62 on leaf area development increased and a significant difference was found between fertilised and non fertilised leek. At final harvest differences between all three treatments were significant and a positive correlation was found between leaf area and nitrogen application rate. The canopy closed around the final harvest (LAI = 4) for fertilised leek. For non fertilised leek and the 50 kg N application a closed canopy was not obtained.

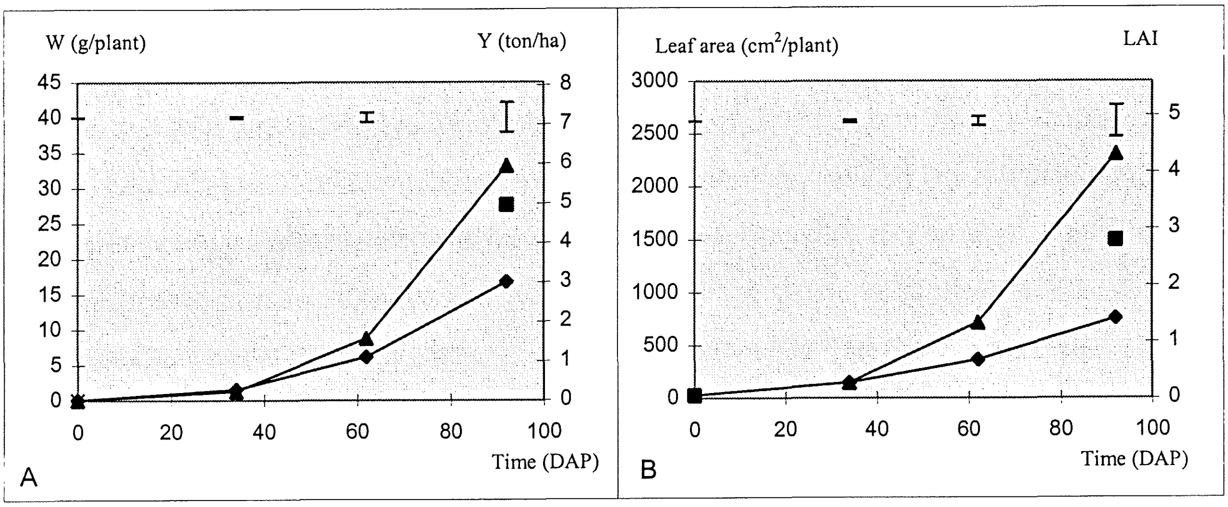


Figure 4.1 Time course of A) W (individual plant weight: g dry matter/plant) and Y (yield: ton dry matter/ha) and B) leaf area (cm^2/plant) and LAI of leek grown in monoculture at nitrogen application rates of 0 (◆), 50 (■), and 200 (▲) kg N/ha. LSD (*p=0.05*) is presented in bars

A similar trend was observed for nitrogen uptake (figure 4.2 A). Initially nitrogen uptake stayed low and only minor differences were obtained between treatments. After 34 DAP, nitrogen uptake increased and uptake rate was rather stable at a level of about 2.9 and 11.7 mg/plant/day (0.5 and 2.1 kg/ha/day) for non fertilised and fertilised leek, respectively. The increase in nitrogen uptake was observed before biomass production increased (figure 4.1) on 62 DAP.

The increased uptake of nitrogen which was observed from 34 DAP on was also reflected in the nitrogen content of leek. (figure 4.2 B). The planting material had a low nitrogen content and after transplanting the nitrogen content increased for all treatments. Since growth rate increased later than nitrogen uptake, nitrogen content of leek that received a fertilizer treatment of 200 kg N remained high and only reduced, when the rate of dry matter production increased drastically after 62 DAP. Nitrogen content of non fertilised leek decreased earlier.

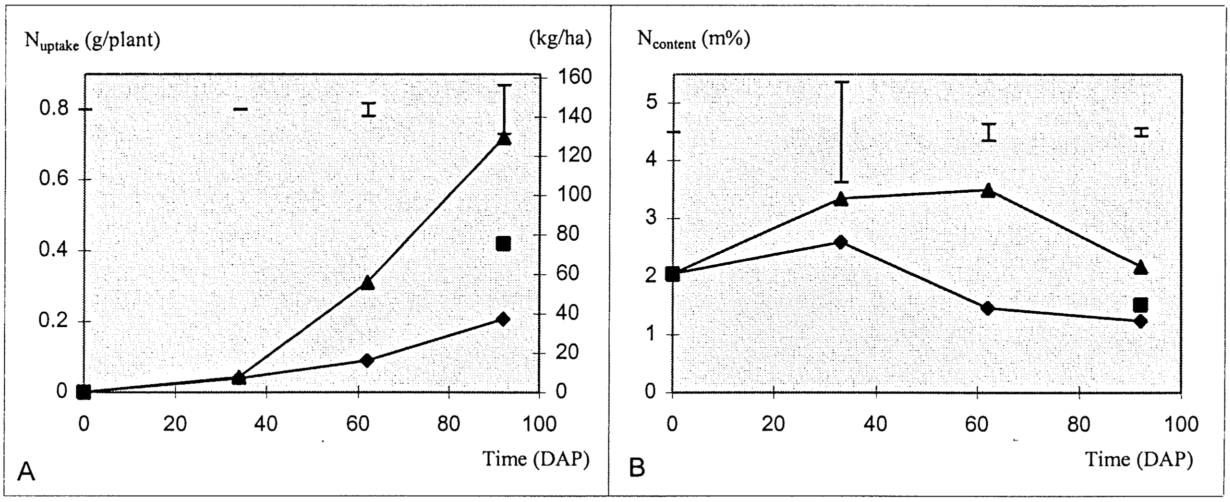


Figure 4.2 Time course of A) nitrogen uptake (g/plant and kg/ha) and B) nitrogen content (m %) of leek grown in monoculture at nitrogen application rates of 0 (◆), 50 (■), and 200 (▲) kg N/ha. LSD (*p=0.05*) is presented in bars.

4.1.2 Characterisation of growth of celery in monocultures

In figure 4.3A, the time course of biomass development for celery grown in monocultures expressed in g/plant and ton/ha is presented. At the first harvest, biomass production of celery was hardly affected by nitrogen application rate. After the first harvest, growth rate of celery increased to a level of 0.7 and 1.7 g/plant/day (0.06 and 0.14 ton/ha/day) for non fertilised and fertilised celery respectively. Growth rate for both nitrogen application rates remained rather stable till final harvest. At final harvest, biomass production of celery at 50 kg N/ha was found in between biomass production in the fertilised and non fertilised treatments and differed significantly from both.

Leaf area development showed a similar pattern as biomass increase (figure 4.3 B). During the first thirty days a low leaf area index was observed, but after the first harvest leaf area inclined rapidly. Celery reached the stage of a closed canopy earlier than leek; around 70 DAP a LAI of 4 was obtained for fertilised celery. At final harvest also the canopy of the celery which received a fertiliser application of 50 kg N was closed. The non fertilised celery never reached this stage.

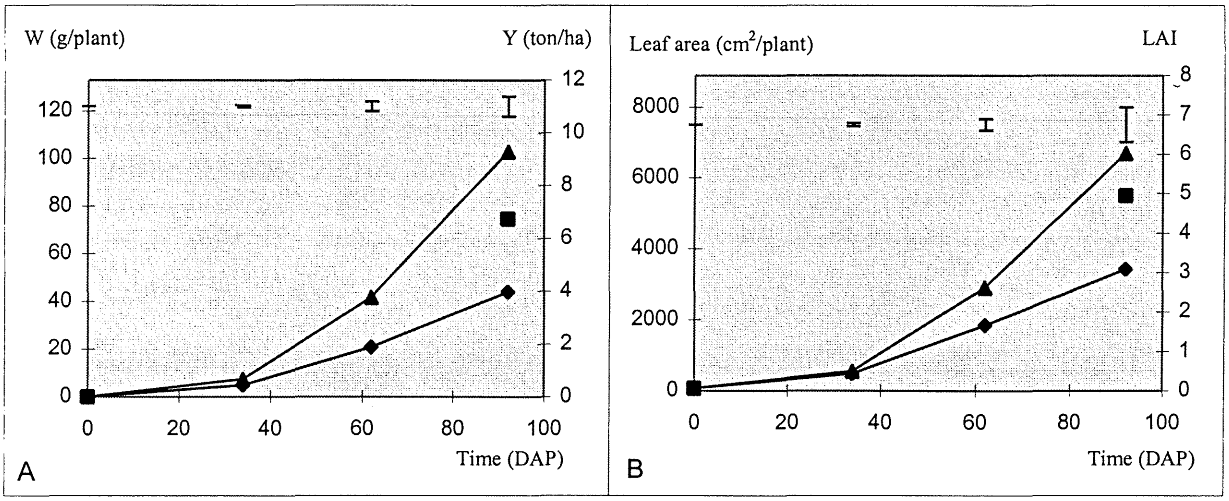


Figure 4.3 Time course of A) W (individual plant weight: g dry matter/plant) and Y (yield: ton dry matter/ha) and B) leaf area (cm^2/plant) and LAI of celery grown in monoculture at nitrogen application rates of 0 (◆), 50 (■), and 200 (▲) kg N/ha. LSD ($p=0.05$) is presented in bars.

The time course of nitrogen uptake is presented in figure 4.4 A. In the early stage of growth hardly any difference between treatments was observed and nitrogen uptake was low. For all treatments nitrogen uptake increased steadily after the first harvest. For non fertilised celery nitrogen uptake rate was 7.2 mg N/plant/day (0.64 kg N/ha/day) and for fertilised celery it was 26.4 mg N/plant/day (2.34 kg N/ha/day). Significant differences between treatments were observed at 62 and 92 DAP. Despite the fact that nitrogen uptake inclined steadily, nitrogen content of celery decreased (figure 4.4 B). Nitrogen analysis revealed that the planting material had a high nitrogen content, which after transplanting declined rapidly for all treatments. On 62 DAP the difference between non fertilised and fertilised celery was significant, but at final harvest only minor differences were observed between nitrogen application levels.

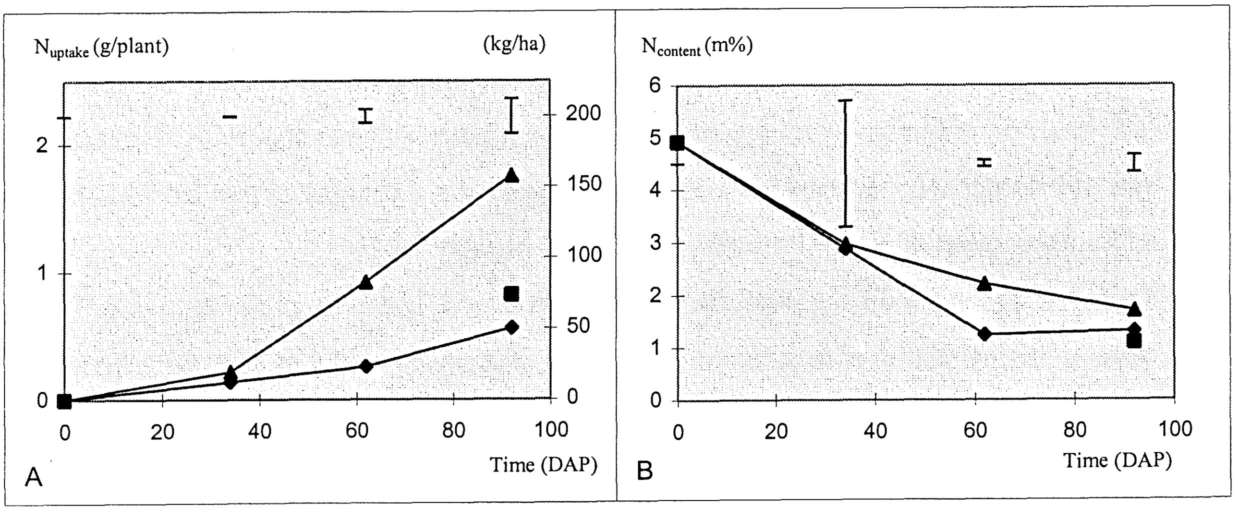


Figure 4.4 Time course of A) nitrogen uptake (g/plant and kg/ha) and B) nitrogen content (m %) of celery grown in monoculture at nitrogen application rates of 0 (◆), 50 (■), and 200 (▲) kg N/ha. LSD (*p=0.05*) is presented in bars

4.1.3 Characterisation of growth of leek in intercrop

In this section growth of leek in intercrop is compared to growth of leek in monoculture. Since in intercrop every second row of leek was replaced by a row of celery, leek in intercrop had a density of 9 plants/m^2 compared to 18 plants/m^2 in monoculture. To facilitate a true comparison between monoculture and intercrop, growth characteristics were expressed on a per plant basis.

In figure 4.5A biomass development for leek grown in intercrop and monoculture is presented. Although leek in intercrop followed the same growth pattern as leek in monoculture, biomass production in intercrop was significantly reduced from 62 DAP on. At final harvest biomass production was reduced with 54, 56 and 61 % for intercropped leek at nitrogen application rates of 0, 50 and 200 kg N respectively.
The reduction of biomass was also reflected in leaf area production (figure 4.5 B); leaf area was significantly reduced in intercrop for all harvests. Leaf area of non fertilised leek did not increase after 62 DAP despite an increase in plant weight.
Stem area was derived from stem diameter (figure 4.5 C). Diameter of the stem is a measure for the quality of leek. In the first stages of growth hardly any difference between intercrop and monoculture was noticed, but from 62 DAP on, differences between intercrop and monoculture were significant. Figure 4.6 gives an indication of the variation in stem area between leek in monoculture and intercrop for the different nitrogen application levels at final harvest. Stem area is divided into 10 classes. From this figure it can be concluded that for all nitrogen application levels leek plants in intercrop were thinner than in monoculture. Also there was less variation in stem area in intercrop than in monoculture.
Another parameter for the quality of leek is stem height (Fig 4.5 D). At 34 DAP leek in intercrop had a significantly higher stem height than leek in monoculture, whereas at final harvest the situation was reversed.

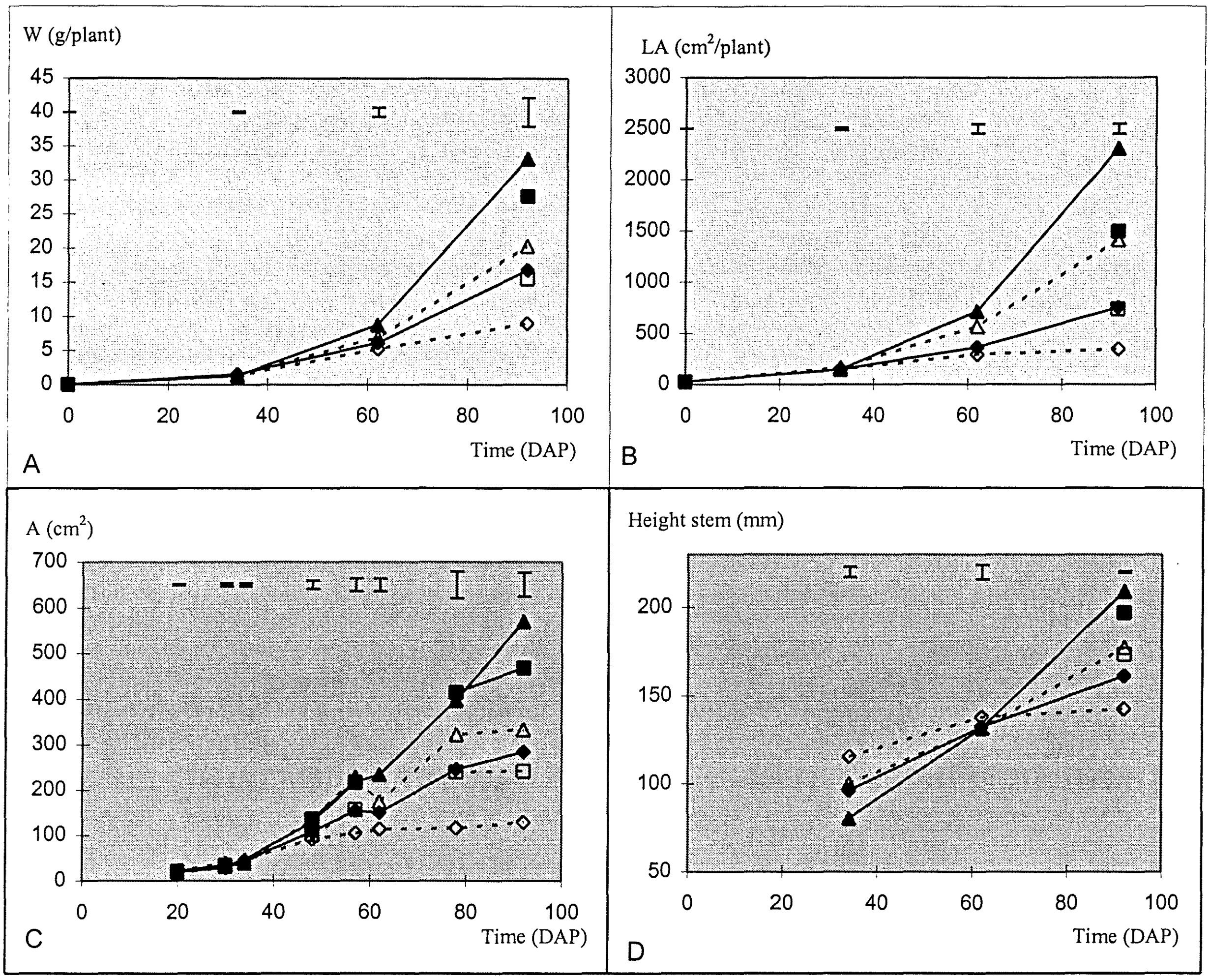


Figure 4.5 Time course of A) W (individual plant weight: g dry matter/plant), B) leaf area (cm^2/plant), C) stem area (cm^2) and D) stem height (mm) for leek grown in monoculture (closed symbols, line) and intercrop (open symbols, broken line) at nitrogen application rates of 0 (◆), 50 (■), and 200 (▲) kg N/ha. LSD (*p=0.05*) is presented in bars

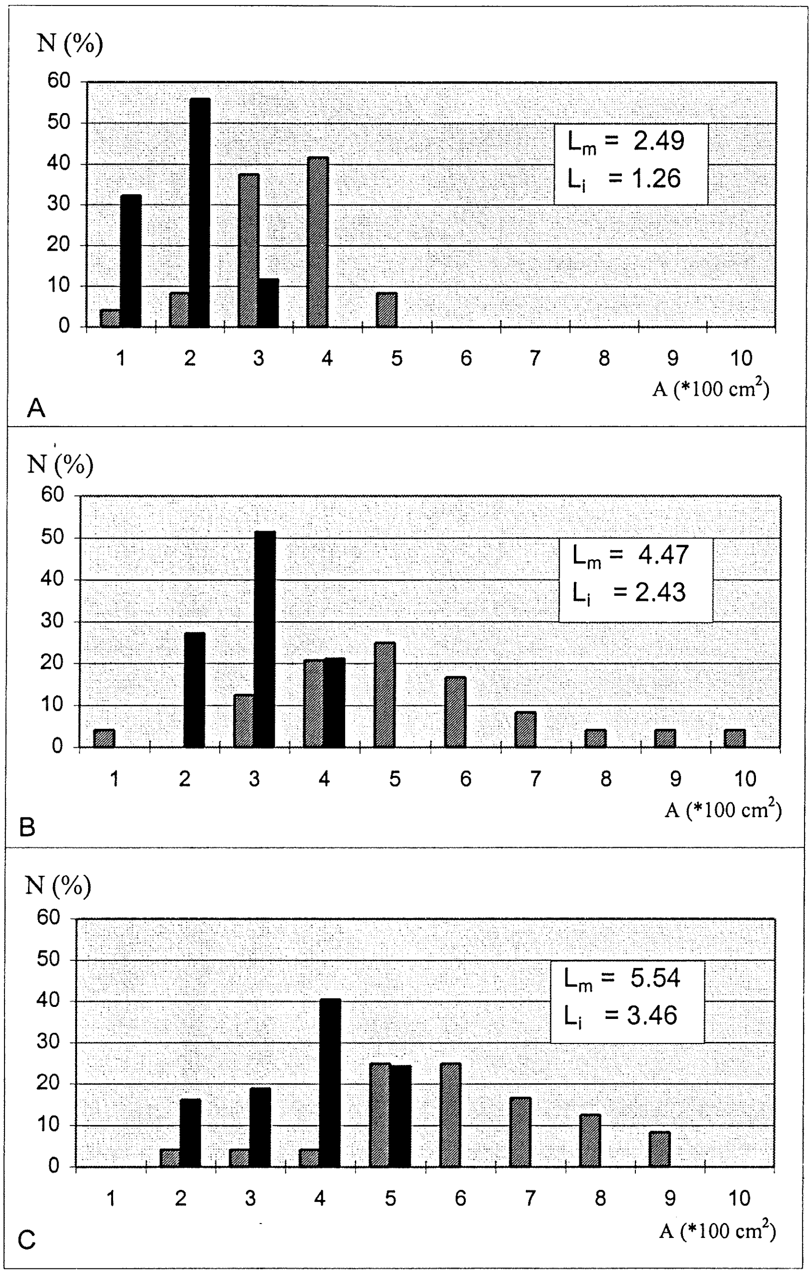


Figure 4.6 Classification of leek plants based on stem area (A; *100 cm^2) at 92 DAP. Plants grown in monoculture (striped) and intercrop (plain) are compared at three nitrogen application rates; 0 (A), 50 (B) and 200 (C) kg N/ha. Median values for monocultures (Lm) and intercrop (Li) are presented in the graph

For nitrogen uptake the same trend was observed as for biomass production and leaf area development (figure 4.7 A). Nitrogen uptake was significantly lower in intercrop than in monoculture for all nitrogen application levels. For non fertilised leek no nitrogen uptake was observed after the first harvest.

The time course of nitrogen content in leek in intercrop and monoculture is presented in figure 4.7 B. Around 34 DAP nitrogen content was highly variable, but from then on leek in intercrop showed a decrease in nitrogen content and nitrogen concentrations in intercrop were significantly lower than in monocrop.

In Figure 4.7 C. the time course of SPAD in intercrop and monoculture is presented. SPAD reflects the chlorophyll content of the plant. In the first growth phase, SPAD values were variable and no clear differences were observed between the treatments. On 48 DAP declining SPAD values were observed for leek in intercrop at nitrogen application rates of 0 and 50 kg N/ha and for non fertilised leek in monoculture. At final harvest though, only the non fertilised intercrop differed significantly from the other treatments.

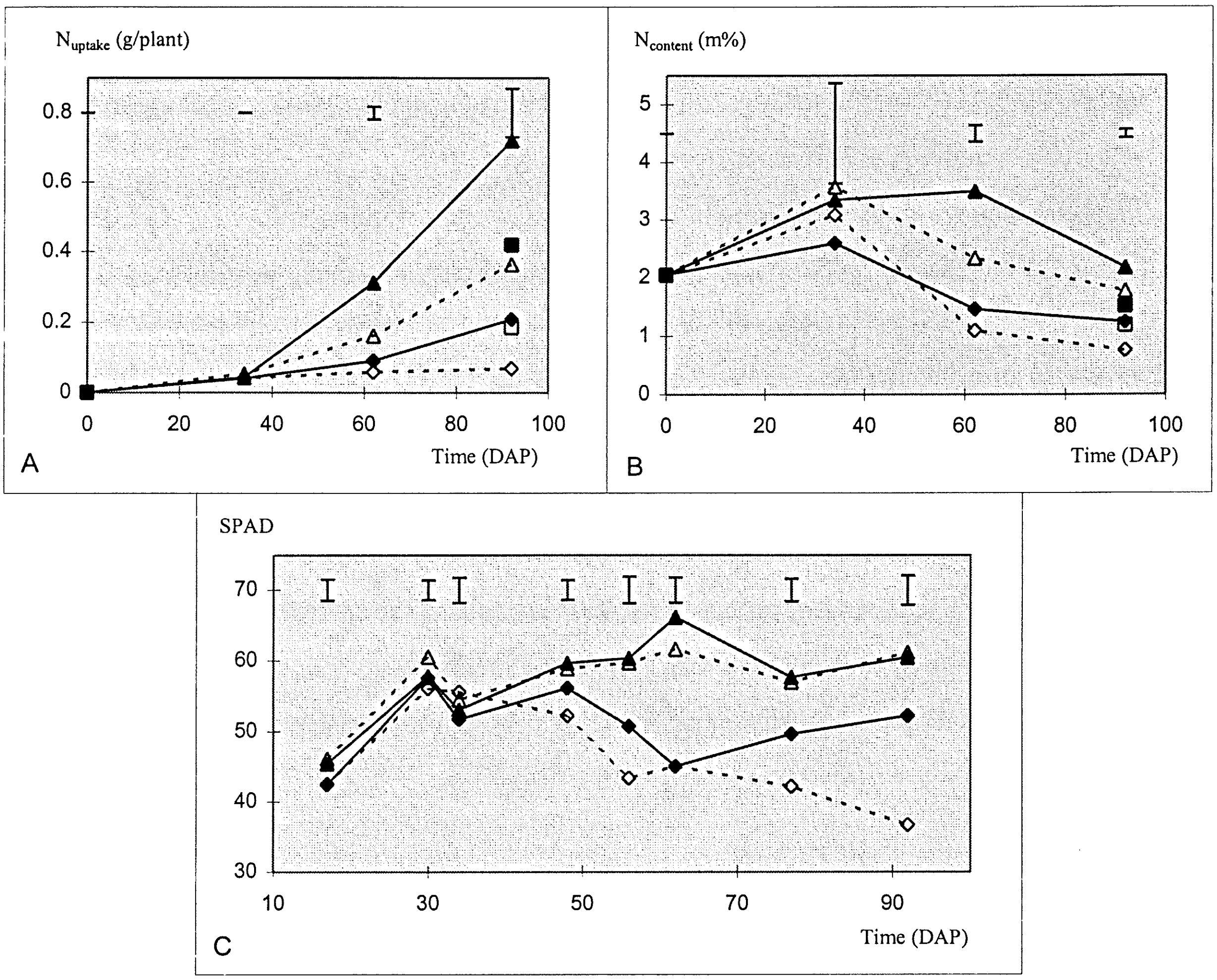


Figure 4.7 Time course of A) nitrogen uptake (g/plt), B) nitrogen content (m %) and C) SPAD of leek grown in monoculture (closed symbols, line) and intercrop (open symbols, broken line) at nitrogen application rates of 0 (◆), 50 (■), and 200 (▲) kg N/ha. LSD (*p=0.05*) is presented in bars

4.1.4 Characterisation of growth of celery in intercrop

Biomass development (g/plant) of celery in intercrop and monoculture is presented in figure 4.8 A. Growth patterns of celery in intercrop and monoculture were comparable. Plant growth however, was significantly higher in intercrop than in monoculture for all nitrogen application rates on 62 and 92 DAP.

A similar pattern was also observed for leaf area development (figure 4.8 B), though not for all treatments. Leek in intercrop at nitrogen application rates of 0 and 50 kg N/ha reached a significantly higher leaf area in comparison with monocultures at the same fertiliser application rates. However, despite a higher biomass production, leaf area development of fertilised intercropped leek did not exceed leaf area in monoculture.

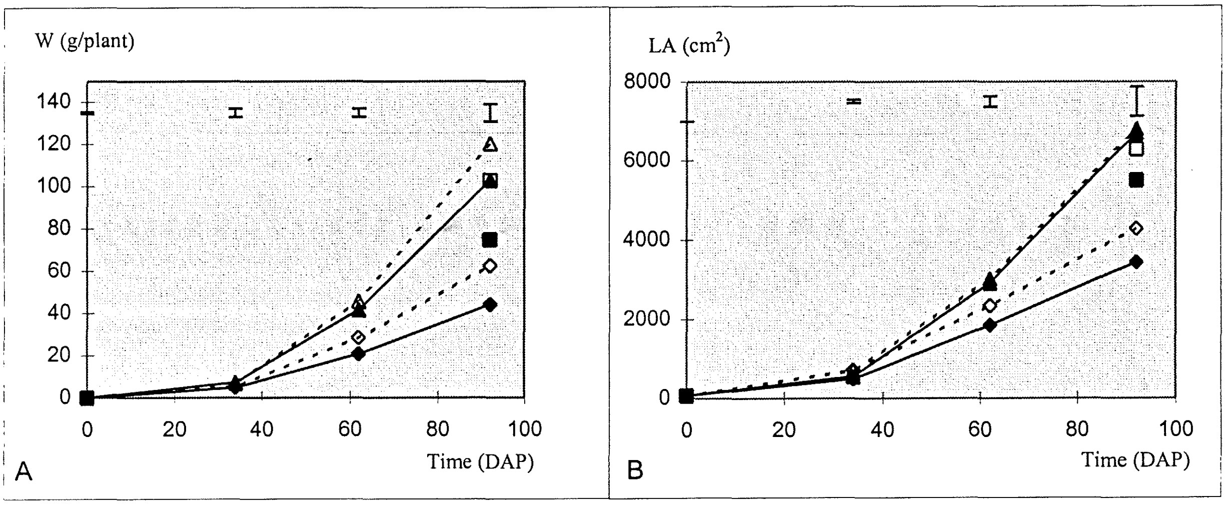


Figure 4.8 Time course of A) W (individual plant weight: g dry matter/plant), B) leaf area (cm^2/plant) for celery grown in monoculture (closed symbols, line) and intercrop (open symbols, broken line) at nitrogen application rates of 0 (◆), 50 (■), and 200 (▲) kg N/ha. LSD (*p=0.05*) is presented in bars

In figure 4.9A development of nitrogen uptake in time is shown. The trend found for biomass production was also observed for nitrogen uptake. On 62 DAP nitrogen uptake in intercrop was significantly higher than in monocrop for all nitrogen application rates. On

92 DAP this difference was still observed for nitrogen application rates of 50 and 200 kg N/ha, but nitrogen uptake of non fertilised celery showed no difference with that of the monoculture. Despite increased nitrogen uptake of celery in intercrop at nitrogen application rates of 50 and 200 kg N/ha, no differences in nitrogen content were observed between inter- and monocrop (figure 4.9 B). At final harvest, nitrogen content of non fertilised celery in intercrop was lower than nitrogen content of the monoculture.
The time course of SPAD of celery in monoculture and intercrop is presented in figure 4.9 C. SPAD values of fertilised celery in intercrop did not differ significantly from the monoculture. In the early growth phase SPAD values for non fertilised celery were rather variable, but from 54 DAP on it was apparent that SPAD values of the intercrop were higher than those of the monocultures.

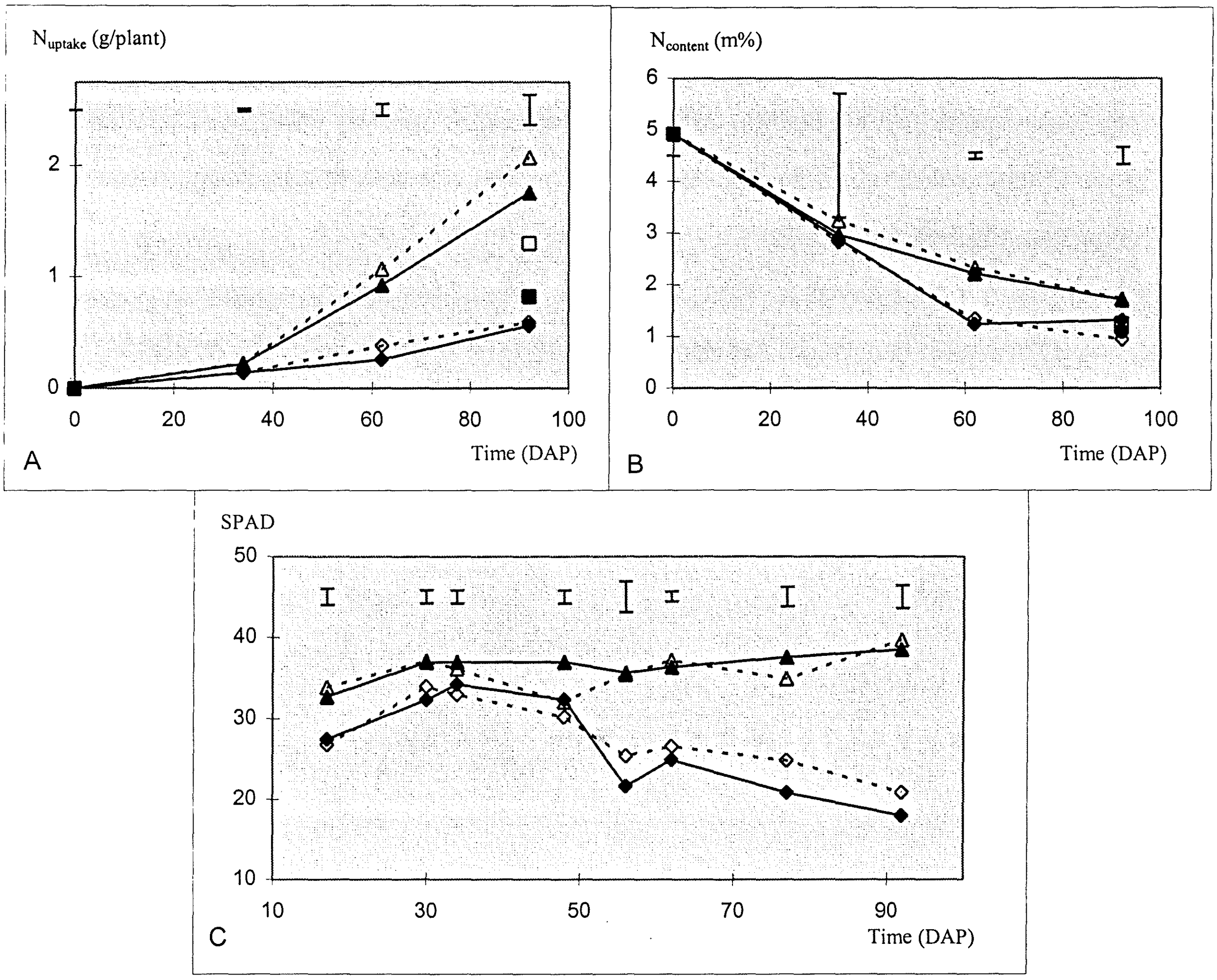


Figure 4.9 Time course of A) nitrogen uptake (g/plt), B) nitrogen content (m %) and C) SPAD of celery grown in monocrop (closed symbols, line) and intercrop (open symbols, broken line) at nitrogen application rates of 0 (◆), 50 (■), and 200 (▲) kg N/ha. LSD (*p=0.05*) is presented in bars

4.1.5 Crop performances of intercrop versus monocultures

LAI and light interception (Fi) of the canopy of the three cropping systems were measured. The results are presented in figure 4.10. From this figure it is clear that regardless of nitrogen application rate, light interception in celery was higher than in intercrop and leek. Light interception in intercrop was closer to that in celery than to light interception in leek monoculture.

The opposite was observed for LAI; at final harvest, LAI in intercrop was closer to LAI in leek monoculture than to that in celery monoculture. The canopies of the fertilised treatments closed at 75 (celery) and 90 DAP (intercrop and leek). The canopies of the crops without fertilizer application did not close at all.

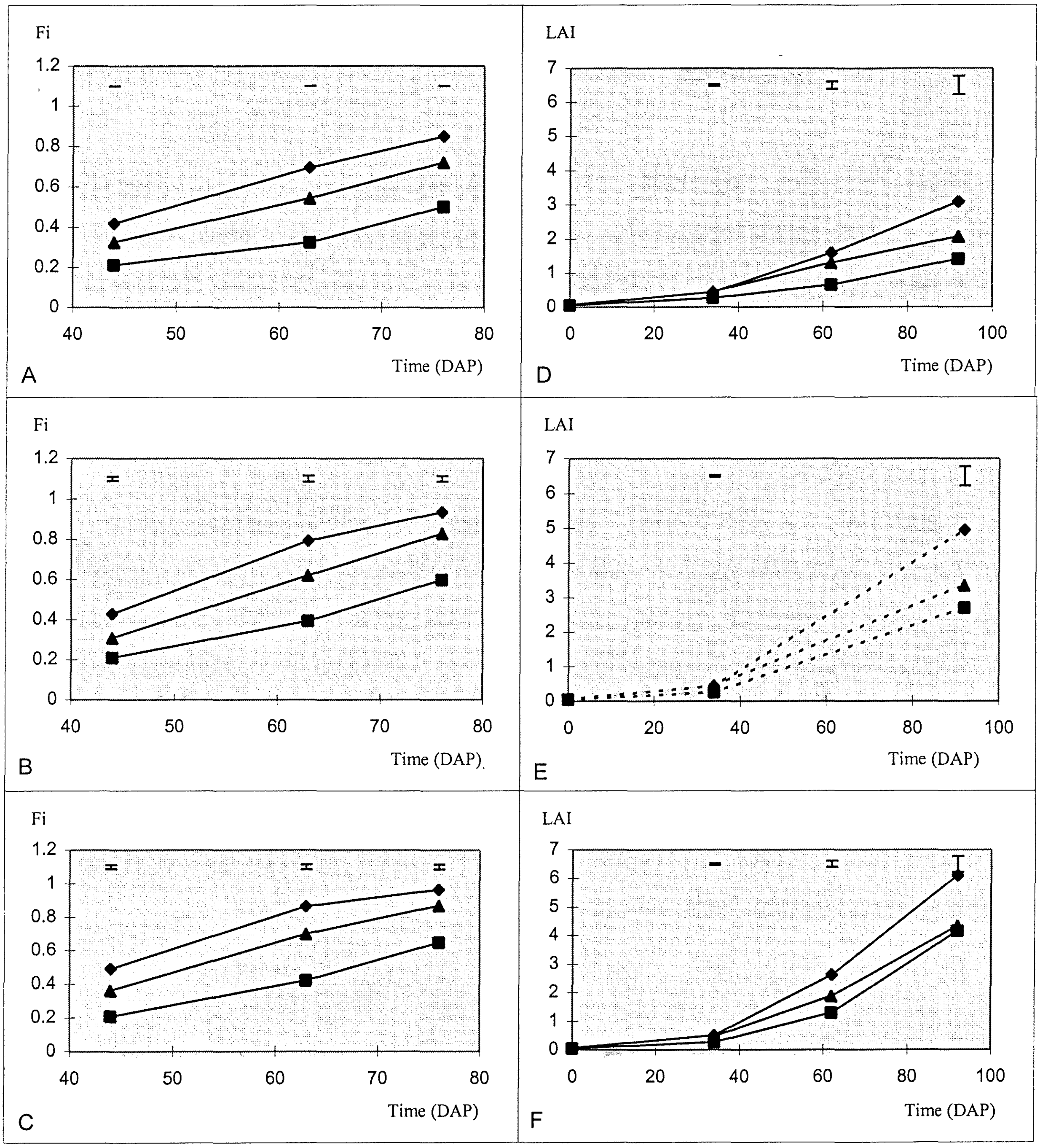


Figure 4.10 Light interception (A,B,C) and LAI (D,E,F) of intercrop (▲), monocultures of leek (■) and celery (◆) at nitrogen application rates 0 (A) 50 (B) and 200 (C) kg N/ha. LSD (*p=0.05*) is presented in bars

In the remainder of this section production of the intercrop will be compared with production of leek and celery when grown in monoculture. This analysis will be done by means of replacement diagrams, which are frequently used in replacement experiments.

In Figure 4.11 relative yields (RY) of leek and celery in intercrop and relative total yield (RYT) are presented. RYT is used as a measure for total production. When 0 and 50 kg N/ha were applied, RYT was 1; the relative yield in intercrop is as high as the yield in monocrop. For the 200 kg N/ha the RYT was significantly lower than 1, which means that yield in intercrop was lower than yield of the monocultures. RY can be used as a measure of competition between leek and celery. From the figure it can be seen that at all nitrogen application rates, RY of leek in intercrop is lower than 50 %. This means that more competition was experienced with celery in intercrop than with leek in monoculture. Yield of leek was lower when the plants had to compete with celery. For celery the opposite was the case; RY of celery was higher than 50%. So in celery the interspecific competition was lower than the intra specific competition. Celery was the strongest competitor of the two crops. There was no variation in relative yield of leek in the different nitrogen application levels, where RY of celery was higher in the 0 and 50 than in the 200 kg N/ha. This competition effect is also reflected in the relative crowding coefficient (k) in Table 4.1. From this table it is clear that at lower nitrogen levels celery was relatively more competitive than at the highest nitrogen level.

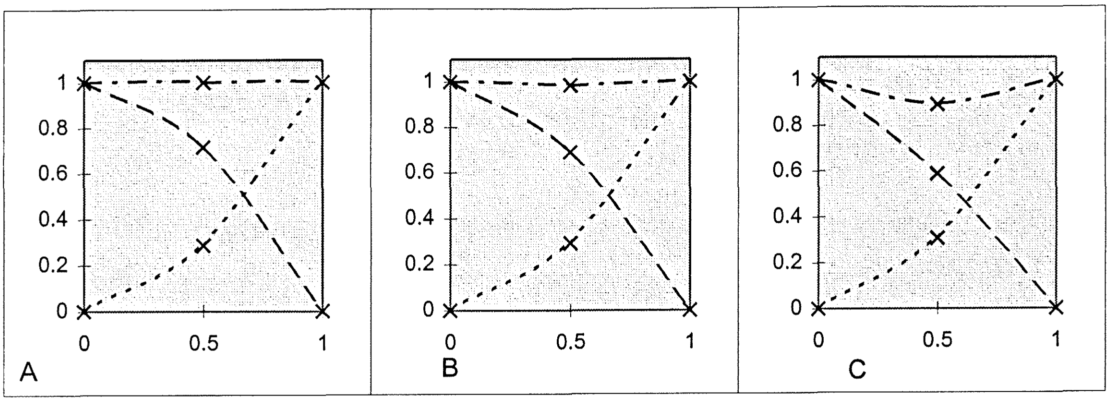


Figure 4.11 Relative yields of leek (dotted line) and celery (broken line) in intercrop and RYT of the intercrop (broken and dotted line) at 92 DAP. Nitrogen application rates of A) 0, B) 50 and C) 200 kg N/ha.

	N_{fert}	L	C	K (Y)
$k_{(Y)}$	0	0.36	2.42	0.87
	50	0.39	2.20	0.86
	200	0.44	1.40	0.62
$k_{(N)}$	0	0.20	1.12	0.22
	50	0.28	3.79	1.06
	200	0.34	1.44	0.49

Table 4.1 Relative crowding coefficient (k) regarding yield and nitrogen uptake for leek and celery in intercrop at 0, 50 and 200 kg N/ha at 92 DAP.

Figure 4.12 presents relative nitrogen uptake of leek, celery and total intercrop at 92 DAP. From this figure it is clear that celery is the strongest competitor for nitrogen at all nitrogen application rates. Nitrogen uptake for leek on a per plant basis in intercrop was lower than could be expected based on the nitrogen uptake in monoculture. There was hardly any variation in relative nitrogen uptake of leek at all nitrogen application rates. Nitrogen uptake of celery showed more variation; relative nitrogen uptake of celery was highest in the application which received a gift of 50 kg N/ha. Relative total nitrogen uptake of the non fertilised intercrop was significantly lower than 1.

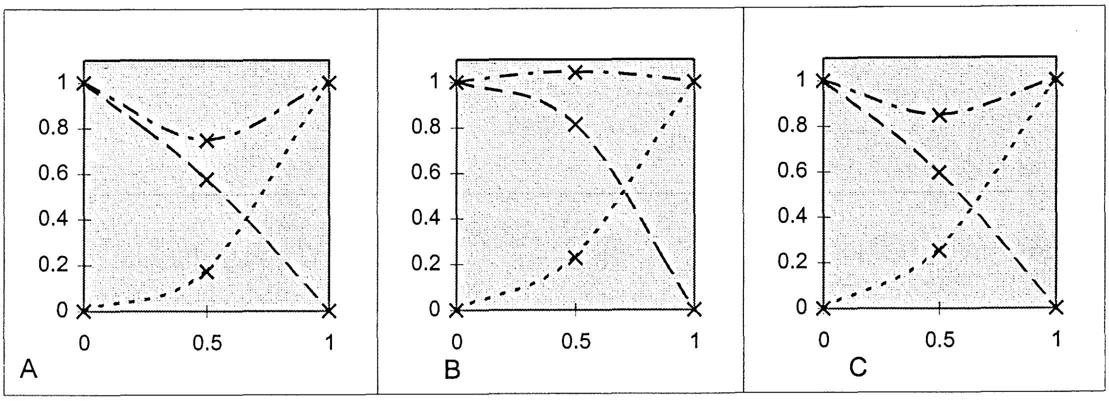


Figure 4.12 Relative nitrogen uptake of leek (dotted line) and celery (broken line) in intercrop and relative total nitrogen uptake of the intercrop (broken and dotted line) at 92 DAP. Nitrogen application rates of A) 0, B) 50 and C) 200 kg N/ha.

Table 4.2 presents nitrogen uptake, total yield and calculated efficiencies in nitrogen use of intercrop and monocultures of leek and celery for final harvest. Treatments which received a fertilizer gift of 0 and 200 kg N/ha had a lower total nitrogen uptake in intercrop than expected based on the monocultures. In these treatments, a lower nitrogen uptake of leek could not be compensated by extra nitrogen uptake of celery. This is also reflected in the recovery of nitrogen in intercrop which was lower than expected based on the monocultures.

Nitrogen uptake in treatments that received a gift of 50 kg N/ha was a similar in intercrop than in monoculture. In this case, lower nitrogen uptake of leek was fully compensated by celery. As a result of this higher uptake by celery, the recovery of nitrogen in the intercrop was higher than was expected based on the monocultures. Celery in monoculture had a higher recovery at 200 than at 50 kg N/ha. Nitrogen recovery of the intercrop and leek in monoculture was lower at the highest nitrogen level.

For the nitrogen application levels of 0, 50 and 200 kg N/ha the total yield in intercrop was equal, slightly higher and lower respectively, than the expected yield based on performance of the monocultures. As a result the utilisation efficiency of the intercrop at 50 kg N/ha was higher and at 200 kg N/ha it was lower than expected. For all treatments, the utilisation efficiency was higher when fewer nitrogen was applied.

Agronomic efficiency reflects the efficiency of the nitrogen that was applied. At both nitrogen application rates, agronomic efficiency of the intercrop was lower than expected based on the monocultures.

Crop	N_{fert} (kg/ha)	N_{upt} (kg/ha)	Y (ton/ha)	Recovery fraction	Agronomic efficiency	Utilisation efficiency
Lm	0	37.37	3.02			
Cm	0	50.39	3.97			
Inter	0	32.76	3.61			
Li	0	6.15	0.81			
Ci	0	26.62	2.81			
Lm	50	75.56	4.97	0.76	0.39	0.51
Cm	50	73.72	6.71	0.47	0.55	1.18
Inter	50	74.99	6.02	0.84	0.48	0.57
Li	50	16.65	1.40	0.21	0.12	0.57
Ci	50	58.34	4.62	0.63	0.36	0.57
Lm	200	129.69	5.97	0.46	0.15	0.32
Cm	200	157.72	9.26	0.54	0.26	0.48
Inter	200	125.83	7.24	0.47	0.18	0.38
Li	200	32.71	1.83	0.13	0.05	0.38
Ci	200	93.12	5.41	0.33	0.13	0.38

Table 4.2 Nitrogen use efficiency (recovery fraction, agronomic efficiency and utilisation efficiency) of celery, leek and intercrop at 92 DAP

4.1.6 Root development of leek, celery and intercrop

On 62 DAP soil core samples of the N_0 were taken to get an indication of the development of the length of the roots of the crops under field conditions. Because it was not possible to distinguish individual leek or celery roots at the sampling position in between the rows in intercrop, all roots were counted. Expected root length density (presented between brackets) based on the monocultures was used for comparison. Data derived from these samples were used for comparison with experiment 2.

Table 4.3 presents root length density (root length per soil volume in cm root/cm^3 soil) at different sampling positions and depths for celery, leek and intercrop. From this table it can be seen that root length density of celery was about three times as high as root length density of leek in monocultures. Regardless of depth, celery in intercrop established less roots than in monoculture and leek in intercrop developed more roots than in monoculture. Production of roots at the sampling position in between the crops in intercrop was slightly higher than expected when compared with the monocultures.

Depth	Position	Crop		
		Lm	Cm	Inter
15-30	in celery row		0.095	0.085
	in leek row	0.034		0.059
	in between row	0.018	0.066	0,055 (0,042)
30-45	in celery row		0.032	0.027
	in leek row	0.014		0.026
	in between row	0.008	0.027	0,016 (0,018)

Table 4.3 Root length density (cm root/cm^3 soil) of N_0 for celery, intercrop and leek at 62 DAP. Expected root length density for the intercrop is presented between brackets

4.1.7 Soil nitrogen content

In table 4.4 the analysis of total soil nitrogen are presented. From this table it can be concluded that little variation was present between total soil nitrogen of the different crops. At a depth of 0 - 0.30 m significant differences between treatments only existed at nitrogen application rate of 50 kg N/ha. In this case, the concentration of total soil nitrogen was significantly lower in intercrop than in the monocultures. At 0.30 - 0.60 m soil nitrogen content was lower, but hardly any differences were observed between treatments. Soil nitrogen content of the intercrop at 200 kg N/ha was significantly lower than in the monoculture of celery.

0 DAP	
Depth	**All**
0-30	0.21
30-60	0.11
0-60	0.16

92 DAP					
Depth	N_{fert}	**Crop**			**Significant difference**
		C	Inter	L	
0-30	0	0.21	0.22	0.22	ns
	50	0.22	0.17	0.23	a / c
	200	0.23	0.23	0.22	ns
30-60	0	0.12	0.12	0.13	ns
	50	0.13	0.13	0.13	ns
	200	0.15	0.12	0.14	a
0-60	0	0.17	0.17	0.18	ns
	50	0.18	0.15	0.18	ns
	200	0.19	0.17	0.18	ns

Table 4.4 Soil total nitrogen content (g N/ 100 g) of intercrop and monocultures of leek and celery at 0 and 92 DAP. Significance (*p=0.05*) is expressed as a, b and c. Significant difference between a) Cm and Int. b) Cm and Lm. c) Lm and Int.

4.2 Experiment 2

In this section root and biomass development of leek and celery in intercrop and monocultures will be described for the rhizotron experiment. During the main part of the observation period it was not possible to make a distinction between roots of leek and celery when grown in intercrop and therefore in the intercrop only the total number of roots was counted.

4.2.1 Root development

Figure 4.13 depicts the development of root intensity (cm/cm^2) and rooting depth of celery, intercrop and leek in time. The two bars on the right side of each graph represent expected and actual root intensity of the intercrop with depth. The expected root intensity of the intercrop is the average of the root intensity of leek and celery grown in monoculture. This averaged value is compared layerwise with the actual root intensity of the intercrop.

Until 54 DAP highest root intensities of celery in monoculture were found in the upper 0.25 m of the soil. Only at 54 DAP, the highest concentration of celery roots was found somewhat deeper, between 0.25 and 0.40 m. Root intensities of leek in monoculture were about three times lower than root intensities of celery, but leek roots had a faster vertical growth than celery roots. Consequently, roots of leek were found more homogeneously distributed over the entire soil profile. On 20, 31, 39 and 54 DAP maximum rooting depths for celery and leek were 0.20, 0.40, 0.50 and 0.75 m and 0.30, 0.60, 0.80 and 0.90 m respectively.

Figure 4.13 E shows, that the overall root intensity of the intercrop at 55 DAP is about the same as the expected root intensity. Position of the roots however is quite different. Based on the monocultures, root intensity close to the celery plant was expected to be higher than the intensity close to the leek plant. In the intercrop however, root intensity in the horizontal plane for any depth is rather uniform. This trend already appeared at 39 DAP, but less pronounced. It is also obvious, that the intercrop did not root as deep as expected based on he monocultures from 31 DAP on til the harvest at 60 DAP.

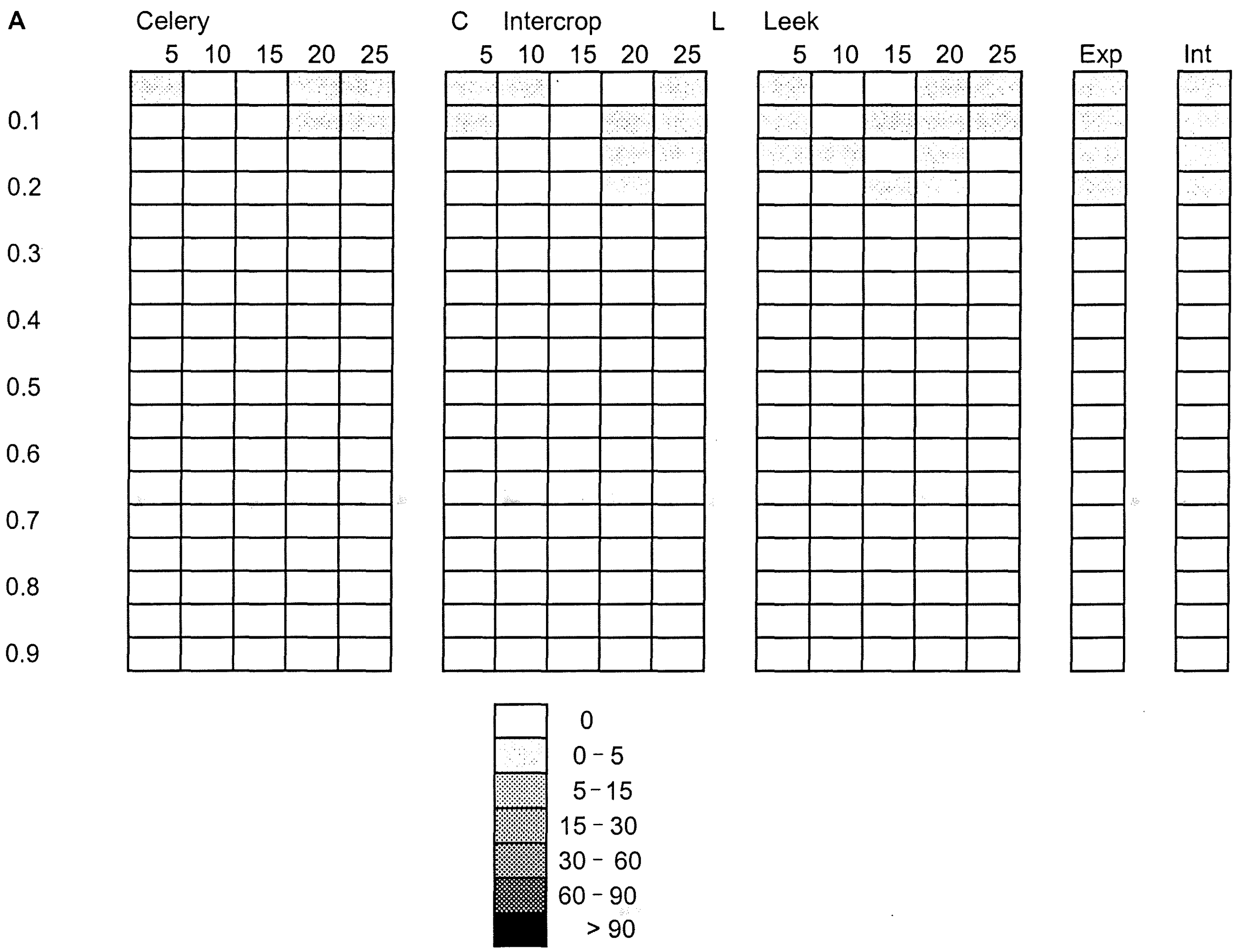
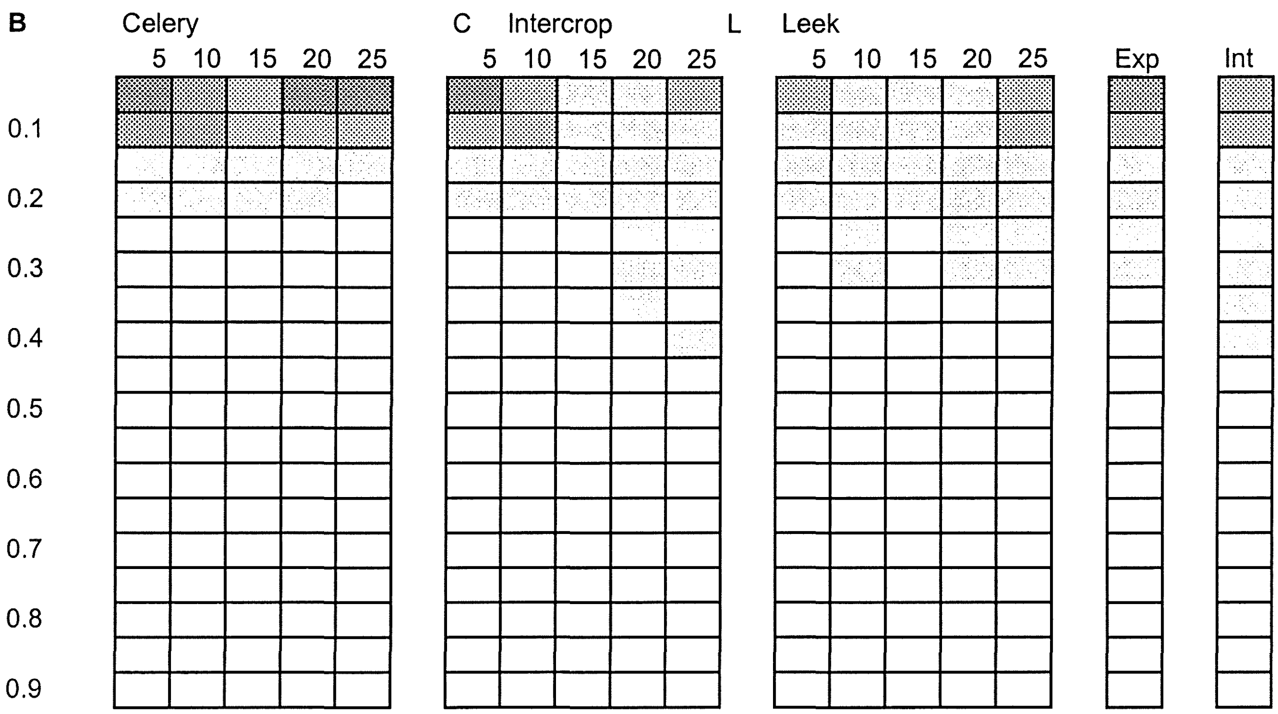


Figure 4.13 A - E Root intensities (cm/cm^2) for celery, intercrop and leek at 11, 20, 32, 39 and 54 DAP. In intercrop, C indicates where celery was planted, L indicates where leek was planted


B
Celery
C Intercrop L
Leek
5 10 15 20 25
Exp
Int
0.1
0.2
0.3
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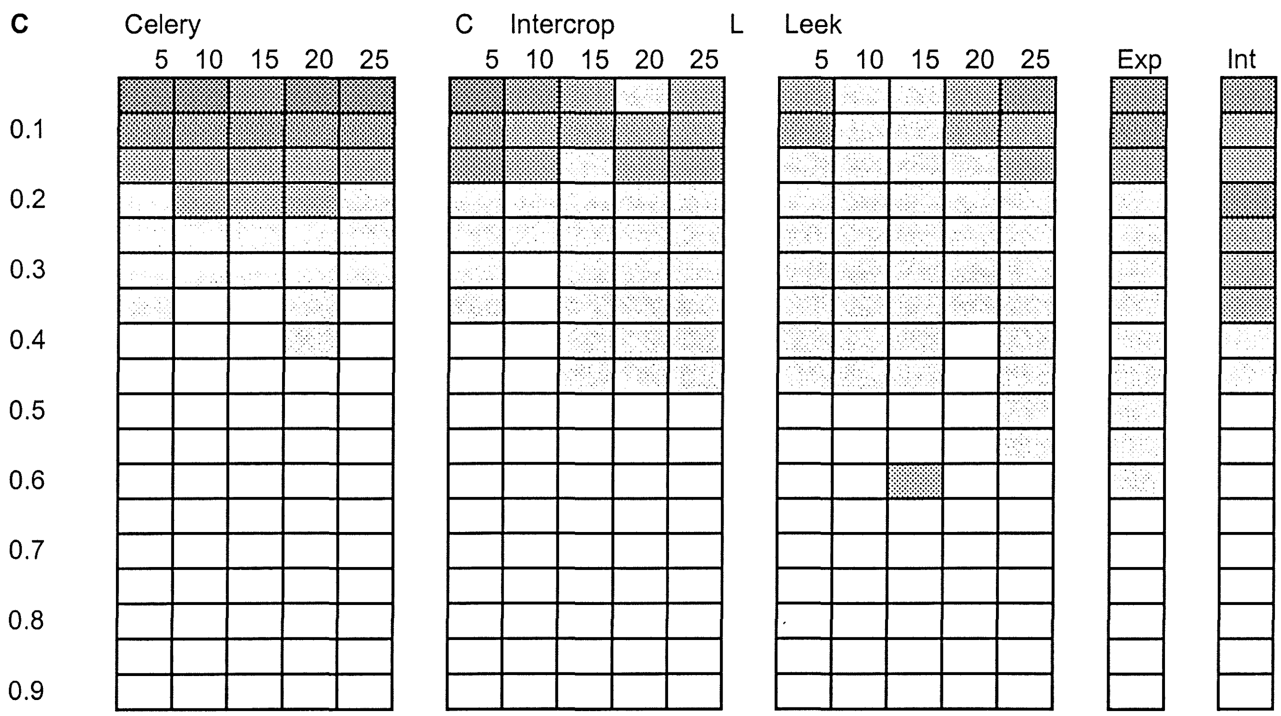
0.6
0.7
0.8
0.9


C
Celery
C Intercrop L
Leek
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0.1
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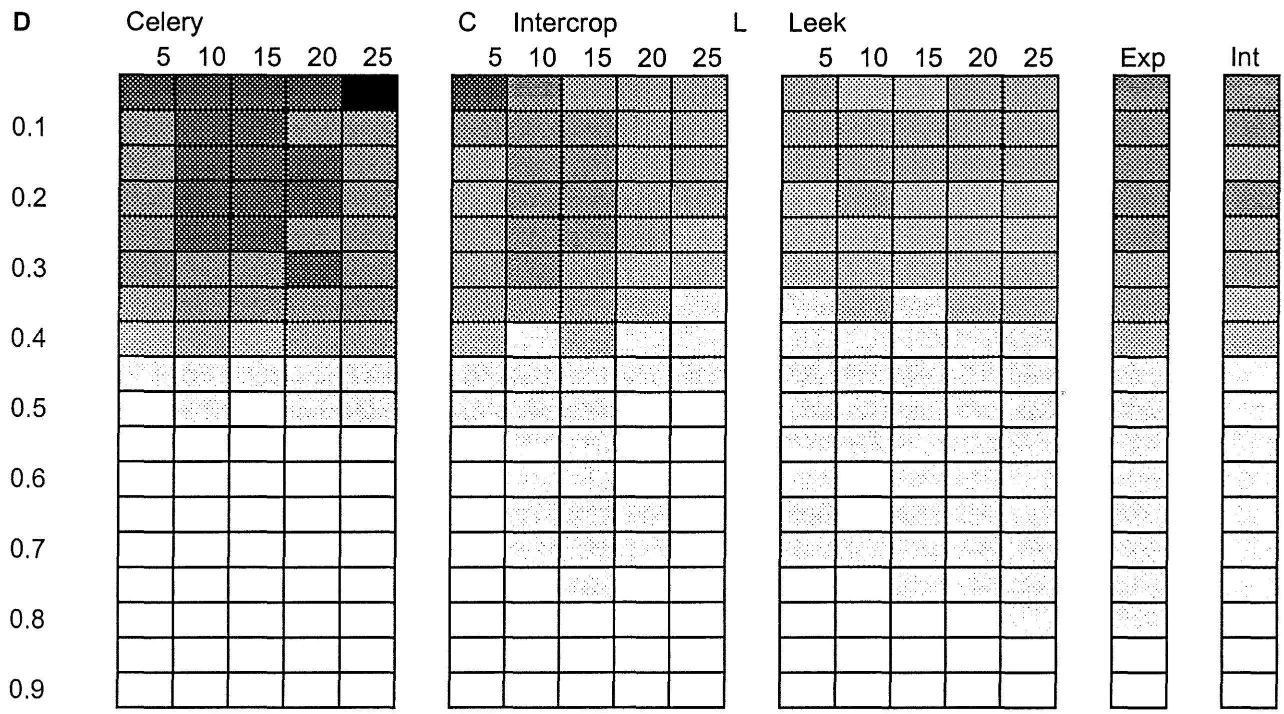
D
Celery
C
Intercrop
L
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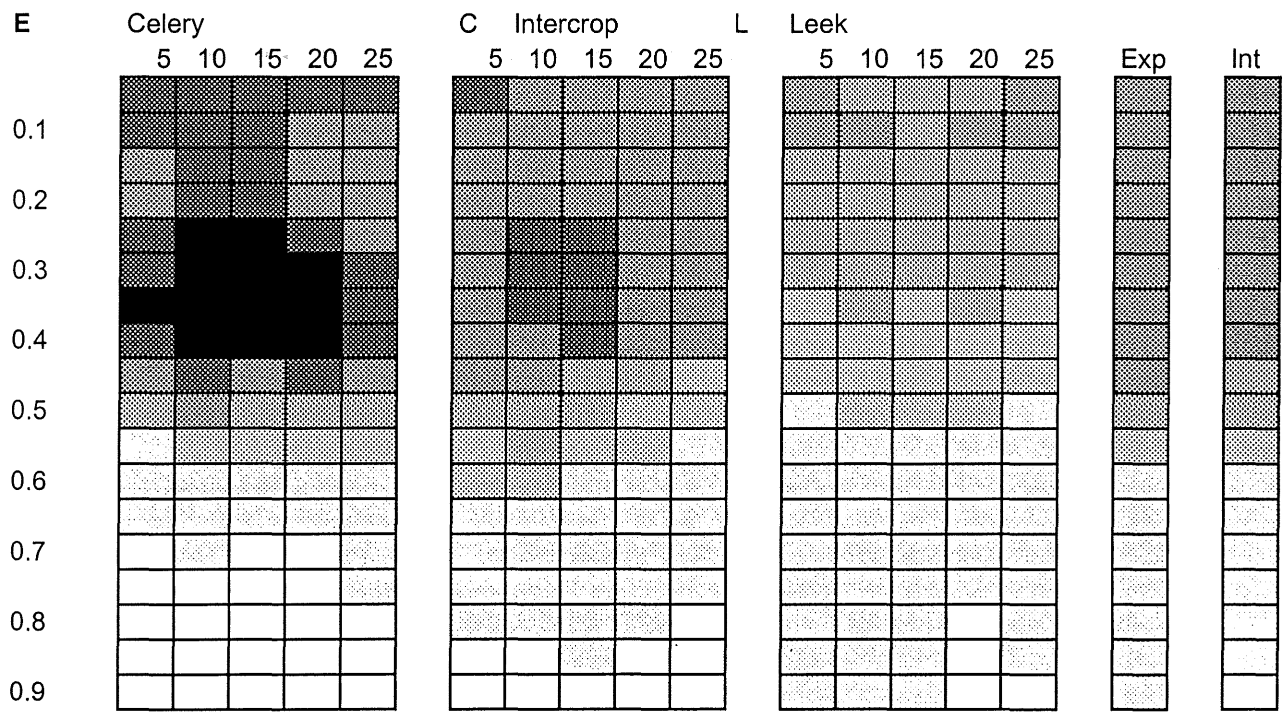
5 10 15 20 25
5 10 15 20 25
5 10 15 20 25
Exp
Int
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9


E
Celery
C
Intercrop
L
Leek
5 10 15 20 25
5 10 15 20 25
5 10 15 20 25
Exp
Int
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

In figure 4.14 root intensities of the intercrop were added for every layer, to obtain actual total root length. In this figure also a value for expected total root length is presented. This value is the average of the total rootlengths of leek and celery in monoculture. Total rootlength of celery was around 2 to 4 times larger than total rootlength of leek during all stages of growth. From the figure it can be seen that during the first four observations (11, 20, 31 & 39 DAP) actual total rootlength of the intercrop was lower than expected rootlength. This difference had disappeared at 55 DAP.

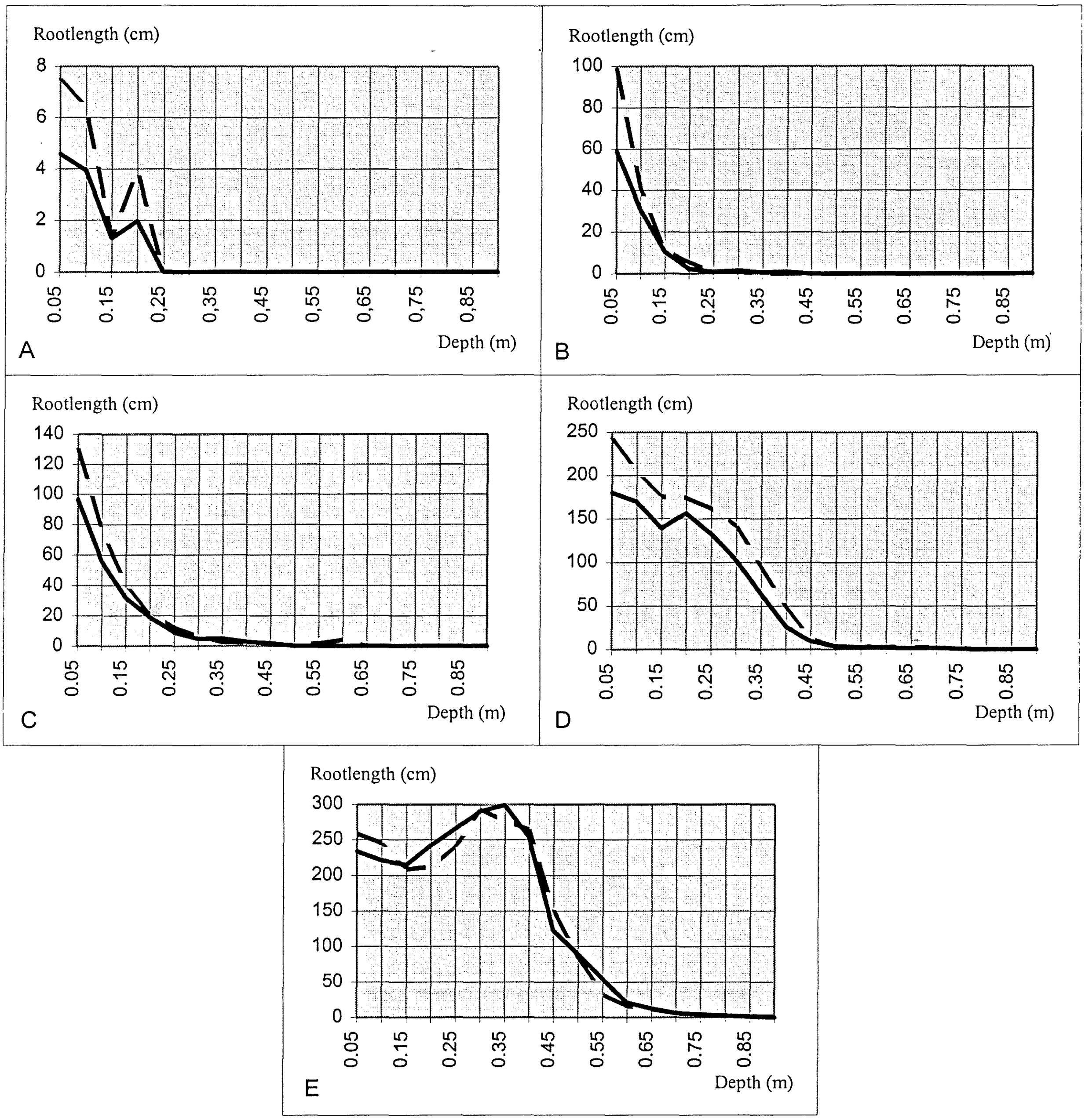


Figure 4.14 A - E Actual total rootlength (bold line) and expected total rootlength (broken line) for the intercrop on 11, 20, 31, 39 and 54 DAP.

Because it was not possible to make a distinction between roots of leek and celery when counting through the glass panels, some of the boxes were harvested at 60 DAP. After harvesting it was possible to separate the rooting systems of leek and celery. The total number of main roots of the rooting systems of leek and celery was counted at various depths. Table 4.5 presents the results of these counts. From this table it can be seen that root development of leek in intercrop was about 50 % of the production of leek roots in monoculture. Celery in intercrop however produced more roots in intercrop than in monoculture.

Crop	Depth	Number of roots / plant	
		mono	inter
L	0	98.00	58.00
	30	38.33	23.33
	60	32.67	9.33
	90	12.33	2.33
C	0	38.00	50.00
	30	30.67	34.67
	60	29.33	26.67
	90	12.67	9.00

Table 4.5 Number of main roots of the plants of leek and celery grown in rhizotrons in monoculture and intercrop at various depths, determined after washing at 60 DAP

4.2.2 Biomass development and nitrogen content

On 60 DAP, shoot- and root biomass was determined and on 96 DAP above ground biomass was determined. The results of these harvests are presented in table 4.6 and 4.7, for leek and celery respectively.

In this rhizotron experiment the same trends were observed as in the field experiment. For both harvests, shoot biomass of leek in intercrop was significantly lower than in monoculture. For celery, the above ground biomass was higher in intercrop as in monoculture, though this trend was not significant.
Total nitrogen uptake of leek in intercrop was significantly lower than in monoculture, although this could not be proved for the individual plant parts. Nitrogen uptake and content in celery intercrop were significantly higher than in monoculture.

		60 DAP		96 DAP	
		Lm	Li	Lm	Li
Biomass (g DM/plant)	shoot	8.08	4,67 *	21.10	14,29 *
	root	3.23	2,04 *		
	total	11.31	6,71 *		
	root/shoot	0.41	0,45 *		
LA (cm^2)				1044.3	692,2 ns
$N_{content}$ (m%)	shoot	2.43	2,25 ns	1.54	1,24 *
	root	1.82	1,94 ns		
	total	2.26	2,15 ns		
N_{uptake} (g N/plant)	shoot	0.20	0,11 ns	0.33	0,18 *
	root	0.06	0,04 ns		
	total	0.26	0,14 *		

Table 4.6 Biomass production (g/plant), LA (cm/plant), nitrogen content (m %) and nitrogen uptake (g/plant) of leek grown in monoculture and intercrop harvested on 60 and 96 DAP. Significant differences between monoculture and intercrop are presented as *, non significant differences were indicated with ns

		60 DAP		96 DAP	
		Cm	Ci	Cm	Ci
Biomass	shoot	11.62	18,05 ns	22.58	32,27 ns
(g DM/plant)	root	8.39	9,42 ns		
	total	20.00	27,48 ns		
	root/shoot	0.72	0,53 *		
LA (cm^2)				228.40	339,8 ns
$N_{content}$ (m%)	shoot	1.85	2,41 *	1.03	1,05 ns
	root	1.53	1,97 *		
	total	1.69	2,26 *		
N_{uptake} (g N/plant)	shoot	0.21	0,44 *	0.23	0,34 ns
	root	0.12	0,18 ns		
	total	0.34	0,62 *		

Table 4.7 Biomass production (g/plant), LA (cm/plant), nitrogen content (m %) and nitrogen uptake (g/plant) of celery grown in monoculture and intercrop harvested on 60 and 96 DAP. Significant differences between monoculture and intercrop are presented as *, non significant differences were indicated with ns

Figure 4.15 presents the time course of SPAD of leek and celery in intercrop and monoculture and the stem area of leek in intercrop and monoculture. For SPAD of leek and celery no significant differences were observed between intercrop and monoculture. Stem area of leek in intercrop was significantly lower at final harvest.

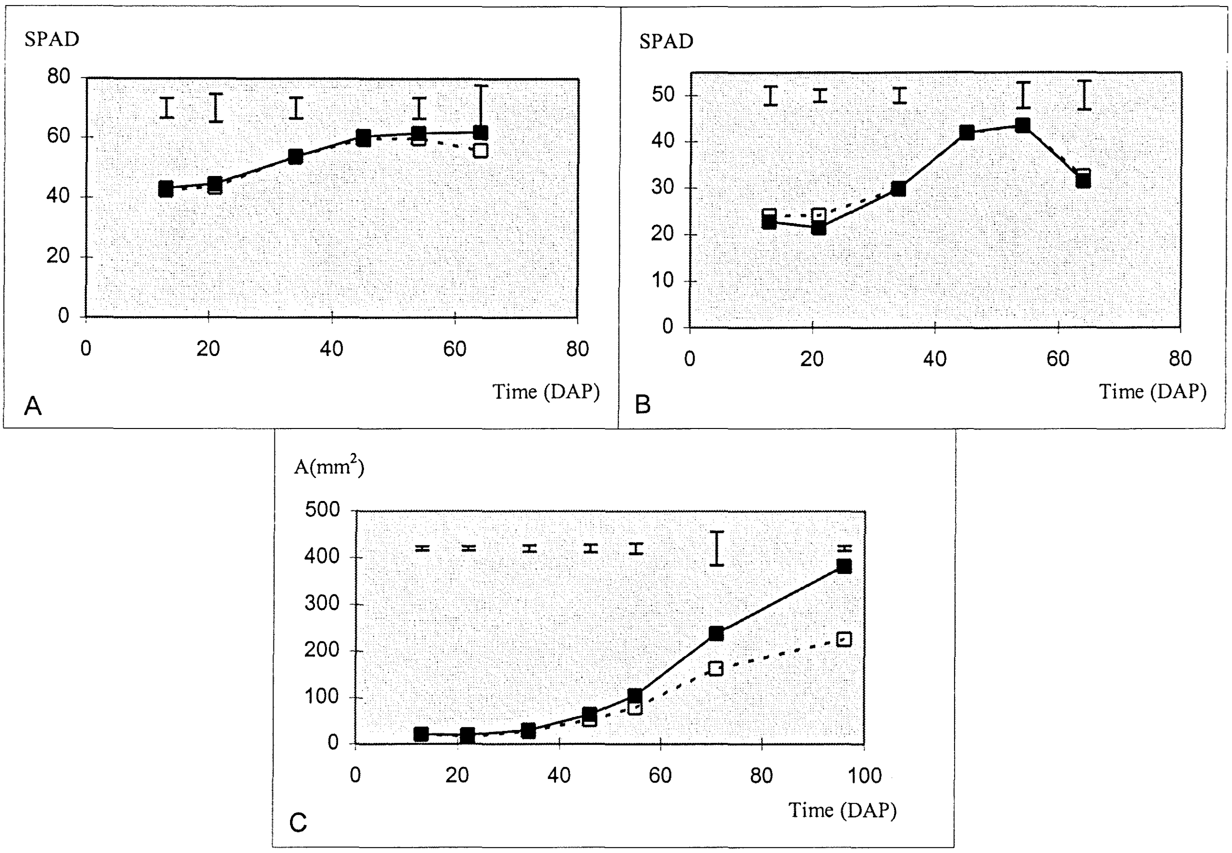


Figure 4.15 Time course of SPAD of leek (A) and celery (B) grown in monoculture (closed symbols, line) and intercrop (open symbols, broken line) and time course of stem area of leek (C) in monoculture (closed symbols, line) and intercrop (open symbols, broken line). LSD (*p=0.05*) is presented in bars

5. DISCUSSION

Nitrogen uptake of leek in monoculture at low nitrogen availability was low, compared to celery under the same circumstances (table 4.2). The amount of nitrogen taken up by leek was limited by the poor development of the above and below ground uptake apparatus. Light interception was limited because the shoot was poorly developed and uptake of nutrients was hampered because the root system was poorly developed. These processes influence each other and limit biomass production.
When nitrogen was not a limiting factor for growth (at 200 kg N/ha), leaf area, nitrogen uptake and biomass production were higher than when no fertilizer was applied. Relative increase of biomass production was lower however than relative increase of nitrogen uptake and leaf area development (fig. 4.1 & 4.2.A). This is due to the fact that light interception did not increase to the same degree as leaf area (fig. 4.10), as a consequence of the morphology of leek. Leek has a very narrow, upright stature as leaves grow rather vertically. Even if the plant produces more leaf area, light interception will only increase slightly. Therefore, the extra amount of nitrogen taken up did not result in a further increase in biomass production, since light was the limiting factor for biomass production.
Nitrogen uptake and light interception of leek at an application rate of 50 kg/ha increased considerably compared to leek without fertilizer application. Light interception was nearly as high as light interception of the crop at 200 kg N/ha (fig 4.10). This resulted in a higher dry matter production and leaf area development than when no fertilizer was applied and very high nitrogen use efficiencies.

Celery at low nitrogen availability had a relatively high nitrogen uptake in comparison with leek (table 4.2). Because light interception was quite good, nitrogen was efficiently used for biomass production. Nitrogen supply was the limiting factor for

biomass production, since light interception and biomass production increased when fertilizer was applied (fig. 4.10).
At 200 kg N, nitrogen uptake of celery was high, but not all absorbed nitrogen was efficiently used for biomass production, therefore, plant material had a high nitrogen content (fig. 4.4.B). Light interception was the limiting factor for biomass production. Plants had fully developed, but due to shading, not all available leaf area was efficiently used for light interception.
It is interesting to note the difference between celery and leek at 50 kg N/ha. Despite a similar nitrogen uptake, biomass production of celery was higher than biomass production of leek (table 4.2). This was possibly caused by better light interception of celery (fig 4.10.B). Furthermore it is also possible that light use efficiency of celery was better than light use efficiency of leek.

In intercrop where no fertilizer was applied, leek took up less and celery took up almost the same amount of nitrogen as in monoculture. Total nitrogen uptake of the intercrop was lower than nitrogen uptake in celery monoculture, even though the potential supply of nitrogen was as high as in monoculture. Biomass production of celery in intercrop was higher however than in monoculture, because the crop could intercept more light due to the weaker competition of leek. Surprisingly, the root system of celery did not seem capable of taking up more nitrogen. Sampling of roots in the field showed that root length density in intercrop close to the celery plant was lower than in celery in monoculture. Root length density in intercrop close to the leek plant was higher however than in monoculture (table 4.3). This was also found in the rhizotron experiment (fig. 4.13.E). The spatial arrangement of celery roots changed, influencing the root system of leek. Leek forms long main roots which hardly branch, whereas celery forms main roots with many branches. In intercrop it was easier for celery to compete with a few leek roots than it was to compete with a highly branched celery root system. Celery roots in intercrop had more space than in monoculture and therefore spread more sidewards, which reduced root length density close to the celery plant and increased the number of roots close to the leek plant. But even though celery

roots spread more sidewards, they did not grow deeper and their number did not increase. Even though the soil volume from which resources were acquired did enlarge, nitrogen uptake did not increase. This might be due to the fact, that celery was close to forming its maximum number of roots, which is indicated by the high root/shoot ratio of the crop in monoculture (table 4.7).
The shift in position of celery roots caused problems for leek however. Leek roots were hampered in development and leek in intercrop developed less roots than in monoculture (table 4.5). This limited nitrogen uptake by leek considerably. This in combination with more light competition and the fact that leek has a very slow initial growth rate (Booij *et al*, 1996), reduced biomass production of leek in intercrop.
At 200 kg N/ha, total relative nitrogen uptake of the intercrop was lower than expected based on the monocultures (fig. 4.11). Nitrogen uptake of leek was considerably lower than in monoculture and nitrogen uptake of celery was higher than in monoculture. But the extra amount of nitrogen taken up by celery was smaller than the reduction in nitrogen uptake by leek. Celery did not take up more nitrogen, because even in monoculture the crop was at this fertilisation level already in a situation of luxury consumption. This is reflected in high nitrogen concentrations (fig. 4.9). Competition for light was severe in this treatment and this was possibly the reason why leek could not take up more nitrogen or develop its above and below ground organs.
At 50 kg N/ha total relative nitrogen uptake was as expected based on the monocultures (fig 4.11). The capacity of the total intercrop to absorb nutrients was comparable to the monocultures, but nitrogen uptake of celery was higher and nitrogen uptake of leek was lower compared with the moncultures. This shift can be explained by competition for light; leek lost the competition for light, so it could not develop roots and shoots as well as in monoculture.

In these experiments, rhizotrons were used for comparison with root samples taken from the field experiment. Taking representative root samples in the field experiment was difficult due to the heterogeneity of the soil. Large stones limited possibilities for taking samples (and also hindered root growth), especially in deeper soil layers. Also in-row planting distance between leek and celery differed and was not always regular in the rows. This caused difficulties in deciding where to take a sample.

A few remarks should be made concerning the use of the rhizotrons and the translation of the results of this rhizotron experiment to the field experiment. In the rhizotrons, competition was different compared to the field experiment, because soil temperature in the rhizotrons was higher and the soil had been sieved in advance, whereas root growth in the field experiment was obstructed by stones and non penetrable soil layers. Also, roots in the rhizotrons can only grow vertically and horizontally, whereas in a field situation roots grow three dimensionally throughout the entire soil. This will possibly lead to an overestimation of rooting depth. A consequence of using glass panels is proliferation of root growth along the glass walls, which leads to an overestimation of the total amount of roots present in the rhizotron (Böhm, 1979). Direct comparison of field and rhizotron experiment was also not possible because in the field experiment a row spacing of 0.30 m was used, whereas in the rhizotron a row spacing of 0.25 m was used. This could enhance competition. Also the level of competition differed; in the rhizotron one celery plant had to compete with one leek plant, whereas in the field one celery plant had to compete with two leek plants, which could reduce competitive effects.

Despite all these difficulties the rhizotron experiment offers good possibilities for qualitative research. Also quantitative research is useful, as in this experiment, but should be used well-considered, since it is highly labour intensive to study roots in such detail. For example, in this experiment it was useless counting roots after 54 DAP, since celery roots were growing abundantly and counts of leek roots in intercrop would disappear in the experimental error.

Is intercropping of leek and celery an option for practise? A better control of pests is achieved (Dobolyi, Städler & Baumann, 1996) and this trial showed that in theory a better control of weeds is possible because light interception (soil cover) is higher compared to leek grown in monoculture (fig. 4.10). But it should be taken into account, that in the intercrop soil cover is not homogeneous and will be lower close to the leek row than close to the celery row. Therefore, weeds in intercrop will mainly occur close to the leek row. Light interception at all fertilisation levels was higher than in the monoculture of leek, which should enhance production. But, as described above, only celery could profit from this. Yield and quality of leek at all fertilisation levels at final harvest is dramatically lower than in monoculture. Minimum quality demands for leek should be met, otherwise it will be more attractive to cultivate monocultures.

Can these problems be overcome and can the intercropping system be improved? Nitrogen efficiencies were highest at a fertilisation level of 50 kg N/ha, but this did not result in a marketable crop, even in monoculture. Figures 4.5 and 4.6 show, that biomass and stem area of leek in intercrop at 50 kg N/ha were considerably lower than in monoculture. Therefore, fertilizer gift should be optimized while maintaining high recovery and nitrogen use efficiencies. As an indication; Booij *et al.* (1996), found a fertilizer recovery of 83 % and a dry matter production of around 9 ton/ha at a fertilisation level of 125 kg N/ha, investigating the effects of nitrogen availability on dry matter production of leek in monoculture. But this is not realistic in intercrop, since celery will consume most of the nitrogen. It can therefore be an option to supply nitrogen fertilizer close to the leek plant, but even this will not solve the problems, because light interception is also limiting crop growth in intercrop. It is necessary to equalise competition between leek and celery, which could be achieved by using lower planting densities of celery. A disadvantage of lower planting densities however, is a lower light interception, resulting in a lower total yield and a crop that is more open, so weeds can establish easier. As can be seen in fig. 4.5, most of the decline in production of leek is achieved in the last stage of growth (after 62 DAP), when competition effects are highest. This is also the growth phase, where leek normally requires the largest amount of nitrogen, because biomass production is large. Competition in this growth phase should be minimal, to obtain maximal biomass production. This could be achieved by not having a competing crop around in this growth phase. When celery would be harvested after around 62 DAP, the advantages of ground cover in the early phase of growth, when leek is very susceptible to weed competition, could be preserved and quality of leek can be improved. But since celery is not marketable when harvested that early, it would be more appropriate to search for a crop with a good ground cover and a shorter growing period. Experimenting with relay cropping would be another option. Leek should be planted in advance of celery, so it can establish without competition. In this growth phase, weed control can easily be accomplished mechanically, since celery is not planted yet. In a later growth phase of leek, celery can be planted in the empty row. One disadvantage is that during a long period soil cover is extremely low, giving weeds a chance to develop. Also the head start of leek is no guarantee that competition effects will be less severe when celery is planted. Relay cropping will also give practical problems, like a higher labour requirement and will therefore possibly not be an option for the practise.

The solution for the problems encountered should be found in a combination of measures. For practical reasons, it is preferable to try to optimise the existing intercrop, before experimenting with a different crop. Optimum fertiliser rate, fertiliser method and planting density should be determined in order to decrease competitive effects on leek.

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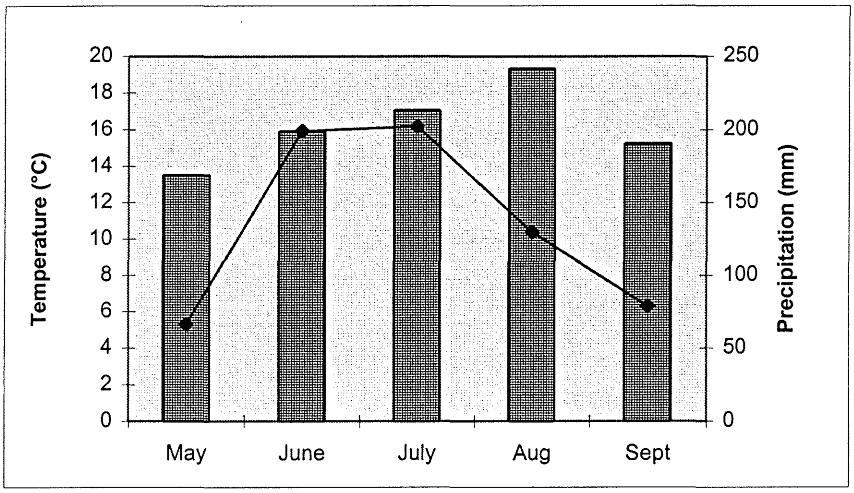
APPENDICES

1. Precipitation and temperature in Wädenswil from April until September 1997
2. Layout experiment 1

APPENDIX 1.



Precipitation and average temperature in Wädenswil from April until September 1997

APPENDIX 2.

Block IV	12 L2	13 L0	36 CL2	37 C2	60 C2	61 L1	84 CL2
	11 C2	14 C	35 CL2	38 CL0	59 C0	62 CL0	83 CL2
	10 L0	15 CL1	34 C1	39 CL0	58 C0	63 CL0	82 L2
Block III	9 CL0	16 CL2	33 C1	40 CL0	57 L2	64 CL1	81 C0
	8 CL0	17 CL2	32 CL2	41 CL0	56 C2	65 L0	80 C1
	7 L2	18 C2	31 CL2	42 L1	55 L0	66 C0	79 C2
Block II	6 L0	19 CL2	30 C0	43 C2	54 L2	67 C2	78 CL0
	5 C0	20 CL2	29 L0	44 L1	53 CL0	68 CL2	77 CL0
	4 C1	21 CL1	28 C2	45 L2	52 CL0	69 CL2	76 C0
Block I	3 CL0	22 C0	27 L0	46 C0	51 CL1	70 CL0	75 C2
	2 CL0	23 L1	26 CL2	47 C2	50 L0	71 CL0	74 CL2
	1 C	24 L2	25 CL2	48 C2	49 C1	72 L2	73 CL2

Experimental design with plot number, crop combination and fertilisation level