Root growth and development of maize during the juvenile stage -rhizolab experiments in 1992 and 1993-

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Summary

The spatial and temporal distribution of maize roots was studied in four experiments in the Wageningen Rhizolab in 1992 and 1993. Root densities showed steep gradients in both the horizontal and vertical plane. Limited amounts of soil mineral nitrogen (SMN) in the proximity of the row, slightly promoted root extension and, consequently, weakened gradients.

Dry matter yield (DMY) of 53 days old maize seedlings responded positively to nitrogen (N). DMYs were 150-335 kg per ha higher if fertilizer N was placed next to the plant row instead of broadcast. Placement between the rows, however, had a similar effect on DMYs in 3 out of 4 experiments. Apparently, root length density distribution and SMN availability matched N demand from the shoot sufficiently. Consequently, the application method of N had only minor effects under the prevailing conditions.

N recoveries by the crop were higher for fertilizer placed next to the row than for broadcast fertilizer. In 3 out of 4 experiments a considerable fraction of the fertilizer N was lost. Recoveries based on the difference method were similar to those based on isotopic dilution.

Samenvatting

In 1992 en 1993 is met behulp van 4 proeven in het Wageningen Rhizolab onderzocht hoe maïs een bodemprofiel in de loop van de tijd doorwortelt. Worteldichtheden vertoonden sterke gradiënten in het horizontale en verticale vlak. Een geringe beschikbaarheid van minerale bodemstikstof (MBN) nabij de plantrij, leidde tot een wat sterkere doorworteling hetgeen de gradiënt verkleinde.

De drogestofopbrengst (DSO) van 53 dagen oude maïsplanten was 150-335 kg per ha hoger bij plaatsing van N naast de rij dan bij breedwerpige bemesting. Plaatsing tussen de rijen, echter, had in 3 van de 4 proeven een vergelijkbaar effect op de DSO. Kennelijk waren de beworteling en beschikbaarheid van MBN voldoende om in de N-behoefte van de spruit te voorzien en was de invloed van de toedieningswijze onder de gegeven proefomstandigheden slechts beperkt. In 3 van de 4 proeven ging een aanmerkelijk deel van de kunstmest-N verloren.
De N-terugwinning in het gewas was het hoogst bij plaatsing naast de rij en het geringst bij breedwerpige bemesting. De terugwinning, berekend op basis van de verschilmethode, was ongeveer gelijk aan de terugwinning op basis van de gemeten isotopenverdunning.

1. Introduction

Nutrient recovery can be improved by a better synchronisation and synlocalisation of nutrients and roots (De Willigen & Van Noordwijk, 1987). Synchronisation and synlocalisation can be qualified as inadequate if the actual nutrient supply (i.e. the exploitable fraction) is low relative to the potential supply. As a result, the root system may be unable to match the shoot demand unless high nutrient rates are applied. Young maize crops react positively to high rates of nitrogen (N). In addition to this, N recovery of maize crops is generally lower than that of other cereals like wheat and barley. We hypothesize that this may be attributable to an inadequate synchronisation and synlocalisation due to the current row spacings (0.7-0.8 m) in combination with a slow lateral and vertical extension of the root system. Circumstantial evidence is provided by experiments showing a positive response of maize to row application of N (Touchton, 1988; Maidl, 1990; Maddux et al., 1991; Sawyer et al., 1991). Low temperature restricts the specific root length, root growth rate, root functioning and rooting depth (Tardieu & Pellerin, 1991; Engels & Marschner, 1990), as well as the mineralization rate. All these processes have a negative effect on N availability. Although shoot demand for N is decreased by low temperatures as well, root systems may be less able to match shoot N demand in a cold spring, especially as the soil temperature commonly lags behind the air temperature at that stage.

There is a need for root observations to evaluate the aforementioned hypothesis. If root observations are made at all in fertilizer experiments, they usually take place around anthesis and focus on root length density gradients with depth. Observations during the juvenile stage and directed to lateral gradients are less common, however. We have tried to fill this gap in knowledge by carrying out four rhizolab experiments in 1992 and 1993.

2. Materials and methods

2.1. Layout

The experiments took place in four compartments of the Wageningen Rhizolab. Each compartment consisted of a container (length x width x depth = 1.25 m x 1.25 m x 1.70 m) filled with soil. The upper 70 cm layer of the compartments was filled with a sandy soil with a low organic matter content. The 70-170 cm layer consisted of coarse sand containing hardly any organic matter. Chemical soil fertility of the upper horizon is shown in Table 1, soil bulk density and porosity of both horizons in Table 2.

Eleven cylindrical glass minirhizotrons were installed horizontally at depths of 5, 10, 15, 20, 30, 45, 60, 85, 100, 120 and 150 cm and 16 ceramic cups, 16 RHIZON SSS artificial roots (Meijboom & Van Noordwijk, 1992), 10 capacitance moisture sensors and 18-23 thermo couples (in only one compartment) at depths of 5, 15, 25, 40, 60, 85, 115 and 150 cm. Installation took place while containers were being filled with soil. During this procedure the soil was recompacted constantly to a bulk density of approximately 1.37 kg l^{-1} each time a new layer of approximately 5 cm was put in. Additional information about the Wageningen Rhizolab and procedures is presented in Van de Geijn et al. (1994) and Smit et al. (1994).

In each layer, ceramic cups and RHIZON SSS tubes were allocated to positions exactly below the plant rows and in between. Samples from both positions were analysed separately except for the 85, 115 and 150 cm depths. RHIZON SSS tubes under the row were oriented in such a way that approximately 15 cm at each side of the row were sampled, those between the rows in such a way that the mid 30 cm were sampled.

Capacitance moisture sensors at depths of 5 and 15 cm were also sited exactly below the planting row and between the rows. At lower depths sensors were allocated randomly either to a position below the row or between the rows.

In total four experiments were carried out during the 1992-1993 period. Before starting a new experiment, the soil was excavated and the described installation procedure repeated in order to rule out any residual effects on subsequent experiments. Excavated soil from the two experiments in 1992 was thoroughly mixed and sieved and used for a second time for the two experiments in 1993.

Table 1. Chemical soil fertility of the top soil at the onset of the experiments

horizon	layer (cm)	pH-KCl	humus (%)	N-total (%)	P-water	K-HCl	MgO
top soil	0-70	5.5	3.5	0.105	26	9	84

Table 2. Average soil bulk density (BD, kg l-1) and porosity (PO, %)

treatment *	layer (cm)	experiment number:							
		1		2		3		4	
		BD	PO	BD	PO	BD	PO	BD	PO
C	0-70	1.39	47.5	1.30	51.1	1.37	47.0	1.36	47.6
IR	0-70	1.40	47.4	1.29	51.5	1.39	46.3	1.35	47.6
B	0-70	1.41	46.9	1.30	51.0	1.39	46.3	1.37	46.9
R	0-70	1.42	46.4	1.33	50.0	1.39	46.3	1.37	47.1
C	70-170	1.58	40.5	1.58	40.5	1.58	40.5	1.58	40.5
IR	70-170	1.52	42.5	1.52	42.5	1.52	42.5	1.52	42.5
B	70-170	1.57	41.0	1.57	41.0	1.57	41.0	1.57	41.0
R	70-170	1.59	40.1	1.59	40.1	1.59	40.1	1.59	40.1

* C=control, IR=placed fertilizer between the rows, B=broadcast fertilizer, R=placed fertilizer next to the row

2.2 Treatments

Four treatments were randomly allocated to the four rhizolab compartments each time that a new experiment was started (Appendix 1). Treatments consisted of a control plot (0 N) and three plots that received 50 kg N ha^{-1}, either banded at a depth of 7 cm between the rows (half the rate along the two outer sides of the compartment), banded at a depth of 7 cm at one side of the row (4 cm from the row) or applied as a broadcast dressing. The latter was mixed through the upper 10 cm layer. ^{15}N depleted (999.9 g ^{14}N per kg) ammonium nitrate (350 g N per kg) and ^{15}N depleted (999.9 g ^{14}N per kg) ammonium sulphate (212 g N per kg) was used in 1992 and 1993, respectively.

Supplementary phosphate and potassium fertilizers were applied to all four N-treatments and mixed through the soil (0-20 cm) prior to filling the containers. Fertilizer rates amounted to 100 kg P_2O_5 and 300 kg K_2O ha^{-1}.

2.3 Crop husbandry

Maize was planted following fertilizer applications at a density of 256.000 plants ha^{-1} and thinned within 1 week after emergence to 128.000 plants ha^{-1} (20 per rhizolab compartment). Plant rows were located perpendicularly to the minirhizotrons. Row distance was set at 60 cm in order to obtain a certain symmetry around the imaginary centre of a rhizolab compartment. Weeds were removed manually as soon as they were observed and insects (predominantly wire worms and aphids) were controlled chemically whenever necessary. Circa 9 weeks after planting observations stopped, plants were harvested and compartments were emptied. Names of cultivars and dates of planting, emergence and harvest are presented in Table 3.

Table 3. Cultivars and dates of planting, 50% emergence and harvest

	experiment number			
year	1992		1993	
	1	2	3	4
variety	LG 2080	LG 2080	Mandigo	Mandigo
date of planting	15th April	3th July	15th April	1st July
date of 50% emergence	4th May	6th July	25th April	7th July
date of harvest	23th June	31st August	15th June	30st August
days from planting till 50% emergence	19	3	10	6
days from 50% emergence till harvest	50	56	51	54

2.4 Observations

2.4.1 Roots

Every fortnight, root observations of the top side of the minirhizotron were made by means of a video camera and recorded on tape. At the final observation dates of Experiments 3 and 4 recordings were extended to the lateral and bottom side of the minirhizotron as well. Individual pictures from subsequent positions, 2.5 cm apart, along the minirhizotron pertain to a square area of 1.3 cm x 1.8 cm. Tapes were processed through the human eye by counting the number of intersections and expressing them in numbers per cm^2.

At the end of each experiment, core samples were taken at lateral distances of 0, 15 and 30 cm from the plant row to a total depth of 70 cm with 10 cm increments. Sampling was done in triplicate in each of the four rhizolab compartments. Sand was removed from the samples by washing and sieving, and roots were spread out (submerged in water) on a 1 cm x 1 cm grid (Smit et al., 1994). Grid line crossings were used as an estimate for root length (Tennant, 1975) and values expressed in cm cm^{-3} by dividing by the known volume of the core sample (178.8 cm^3). Data of root length densities from core samples and root intensities as recorded on minirhizotron walls in the proximity of these samples (viz. 3 neighbouring positions), were subjected to regression analysis. Observations at a depth of 45 and 60 cm were pooled. The obtained relationships were supposed to be applicable to preceding observation dates as well.

Only the observations from minirhizotrons at depths of 5, 15 and 45 cm, could be related to core samples from identical depths. Minirhizotron positions from other depths did not exactly coincide with core sampling depths. If so, intensities as determined on minirhizotron walls at depths of 60, 30, 20 and 10 cm were related to average root length densities in core samples of the pooled 50-70 cm, 20-40 cm, 10-30 cm and 0-20 cm layers, respectively.

Minirhizotron observations were presented in a comprehensive tabular form by allocating successive horizontal positions to one out of five lateral distance classes. Class borders were 0 to 4, 4 to 11, 11 to 19, 19 to 26 and 26 to 30 cm for the five successive lateral distance classes.

In order to arrive at more general relationships, root length densities as observed in each of the four experiments were plotted against thermal time instead of days. Thermal time was defined as the summed average soil temperature (depth 15 cm, > 8 °C) after emergence. Data were fitted with a linear response model allowing for a time lag:

$$\text{root length density}_{i,j} = 0 \text{ if heatsum} < l_{i,j} \text{ and}$$
$$\text{root length density}_{i,j} = c_{i,j} * \text{heatsum} \quad \text{if heatsum} >= l_{i,j}$$

with i and j being indices for lateral distance and depth, l being the thermal time needed to arrive in a soil compartment, heatsum being the summed average temperature as defined and c being the ratio between heatsum and root length density.

2.4.2 Shoot development and growth

Shoot development was recorded by regular assessment of the number of fully expanded leaves (i.e. border of leaf collar and sheet clearly visible) and height. Chlorophyll content of the youngest fully expanded leave were assessed non-destructively with the SPAD 502 (Minolta) meter, at least once in each experiment as chlorophyll content is associated with the N status and yield of maize crops (Wood et al., 1992; Piekielek and Fox, 1992). Values pertained to the average of circa 10 measurements per plant and 20 plants per treatment. Circa 9 weeks after planting maize plants were dug out to a depth of approximately 10 cm. Plants were split into roots, stems and leaves and, after sand had been removed from the roots by water and roots had been spin-dried, fresh weight of each fraction was determined. Area of the leaf sheets was assessed and sub samples were dried for 24 hours at 105 °C to determine the dry matter content. ^{15}N contents were assessed with a gass specific mass spectrometer (Europe Scientific) and total N and NO_3-N contents with a TRAACS 800 continuous flow analyse system (Bran Luebbe Analyzing Technologies).

From the 22nd day after emergence, crops of Experiment 3 suffered from paraquat drift from an adjacent field experiment. Visible leaf damage decreased with distance in the order of BC-, R-, IR- and control treatment. Since this may have affected crop performance, the results of Experiment 3 should be treated with utmost care.

2.4.3 Soil

Moisture content and soil temperature (the latter in only 1 of the 4 compartments) were recorded continuously with a data logger. NO_3-N and NH_4-N contents were determined fortnightly by both ceramic cup and RHIZON SSS sampling and by core sampling at the onset and end of each experiment. RHIZON SSS samples were analysed for ^{15}N as well. NO_3-N and NH_4-N were assessed with a TRAACS 800 continuous flow analyse system (Bran Luebbe Analyzing Technologies), ^{15}N was assessed with a gas specific mass spectrometer (Europe Scientific).

2.4.4 Recovery

N recoveries were calculated according to the difference method (equation1) and according to the isotope dilution method (equation2).

Equation 1: N recovery (%) = (N uptake of fertilized crop (kg ha^{-1})-
N uptake of control crop (kg ha^{-1}))
/(0.01 x N rate (kg ha^{-1}))

Equation2: N recovery (%) = ((^{15}N content of control crop (%)-
^{15}N content of fertilized crop (%))x
N uptake of fertilized crop (kg ha^{-1}))
/((0.01 x N rate (kg ha^{-1}) x
(natural ^{15}N content (%) -
^{15}N content of depleted fertilizer(%))

2.4.5 Balance sheet

The difference between mineral N inputs and N outputs per treatment was used as an estimator for net mineralization (i.e. losses and temporarily immobilisation included). Thus net mineralization equals:

(N uptake of crop + soil mineral N at harvest) -
(mineral fertilizer N + soil mineral N before fertilizer application).

2.4.6 Crop growth analysis

Observed differences in growth between treatments were analysed in terms of relative growth rate (RGR), specific leaf area (SLA), leaf weight ratio (LWR) and net assimilation rate (NAR) according to equation3 and equation4.

Equation 3: RGR = (ln(whole plant yield)-ln(seed weight))/(dae) with:
seed weight is 32 kg dry matter per ha and
dae is days between 50% emergence and harvest.

Equation 4: NAR = RGR / (SLA x LWR)

2.4.7 Weather

Aerial temperature at a height of 150 cm and global radiation were obtained from a meteorological station 3 km from the Wageningen Rhizolab. Soil temperature and aerial temperature at a height of 10 cm were collected in situ. Natural precipitation was precluded by a transparent shelter covering all compartments automatically during rainfall events (Van de Geijn et al., 1994). Compartments were irrigated manually during the first 18-48 days of the experiments and automatically with a 10 cm x 20 cm grid drip irrigation system for the remaining period, approximately 4 times a week. Irrigation rate amounted to circa 3 mm per day averaged over experiments, treatments and days.

3. Results

3.1 Weather and physical soil conditions

After emergence, air temperatures were substantially above the long term average except for Experiment 4. Consequently, even the early planted maize crops (Experiments 1 and 3) were not exposed to cold stress (Table 4). Global radiation was higher than normal as well except for Experiment 4 (Table 5). Soil temperature decreased with depth, especially under early planted crops (Figure 1). Difference between average bulk soil temperature and the temperature along the minirhizotron walls at 15 and 60 cm depths, never exceeded 0.4 °C (Table 6). Moisture content was kept between 140-210 g and 150-190 g per kg for the 0-10 cm and 10-70 cm layers, respectively. Moisture content in the subsoil was 50-60 g per kg except for the bottom of the containers where the soil was saturated. No consistent moisture gradient could be observed between the soil volume under the maize row and the soil volume between the rows (Appendix 2).

Table 4. Average daily air temperature (°C) and aerial heat sum (°Cd , >8 °C)

	interval	experiment				long term average	
		1	2	3	4	early*	late*
temperature	planting - emergence	8.7	18.1	11.6	17.6		
	emergence - harvest	16.2	17.9	15.2	15.2		
	planting - harvest	14.1	17.9	14.6	15.5	12.5	16.0
heat sum	planting - emergence	28	40	40	67		
	emergence - harvest	410	556	369	391		
	planting - harvest	438	596	409	459	277	527

* early denotes planting around April 20 and harvesting around June 20 (Experiments 1 and 3), late denotes planting around July 1 and harvesting around August 31 (Experiments 2 and 4)

Table 5. Global radiation (MJ m^{-2} day^{-1}) from May 1st - June 20th (Experiments 1 and 3) and from July 1st - August 31st (Experiments 2 and 4)

interval	year		long term average
	1992	1993	
May 1st-June 20th	19.0	17.7	16.4
July 1st-August 31st	15.7	14.3	14.6

Table 6. Average daily temperature (C) at the soil surface, in the soil and along and in root observation tubes between planting and emergence (p-e), emergence and harvest (e-h) and planting and harvest (p-h)

site	Experiment 1			Experiment 2			Experiment 3			Experiment 4		
	p-e	e-h	p-h	p-e	e-h	p-h	p-e	e-h	p-h	p-e	e-h	p-h
soil surface	10.1	18.5	16.1	20.0	20.0	20.0	-	-	-	-	-	-
soil, -5 cm	10.9	19.7	17.2	22.1	20.7	20.8	13.5	19.0	18.0	21.0	17.9	18.2
soil, -15 cm	10.7	19.4	16.9	22.7	20.8	20.9	12.6	18.5	17.5	20.8	17.9	18.2
soil, -25 cm	10.6	19.1	16.7	22.6	20.8	20.9	12.2	18.1	17.1	20.5	17.9	18.2
soil, -40 cm	10.5	18.6	16.3	22.4	20.7	20.8	13.0	18.2	17.3	20.2	17.8	18.1
soil, -60 cm	10.3	17.8	15.7	21.9	20.7	20.7	11.2	17.1	16.0	19.5	17.8	18.0
along tube, -15 cm	10.9	19.8	17.3	22.8	20.8	21.0	12.2	18.5	17.5	20.0	17.9	18.1
in tube, -15 cm	10.7	19.2	16.8	21.1	20.8	20.8	-	-	-	-	-	-
along tube, -60 cm	10.4	18.0	15.8	21.8	20.9	20.9	-	-	-	-	-	-
in tube, -60 cm	10.5	18.4	16.1	21.2	21.1	21.1	-	-	-	-	-	-

Evapotranspiration as calculated from irrigation, drainage and the change in soil water supply, generally increased with crop age without any obvious differences between treatments (Table 7). On average, evapotranpiration amounted to 1.5, 2.0 and 2.7 mm per day for the first, the second and third 20 day period of each experiment.

Table 7. Irrigation (IRR, mm day^{-1}), drainage (DRA, mm day-1), change in soil water supply (CWS, mm day^{-1}) and calculated evapotranspiration (CET, mm day^{-1})

Treatment:	C			IR			B			R		
period*:	1	2	3	1	2	3	1	2	3	1	2	3
Exp. 1												
days	27	21	21	27	21	21	27	21	21	27	21	21
IRR	0.71	0.99	2.90	0.71	0.99	2.90	0.71	0.99	2.90	0.71	0.99	2.90
DRA	0.32	0.20	0.04	0.24	0.19	0.06	0.35	0.17	0.05	0.32	0.24	0.08
CWS	0.45	0.12	0.20	0.21	0.22	0.24	0.68	0.34	0.24	0.49	0.23	0.21
CET	0.84	0.91	3.06	0.68	1.02	3.08	1.04	1.16	3.09	0.88	0.98	3.03
Exp. 2												
days	18	21	21	18	21	21	18	21	21	18	21	21
IRR	2.17	3.17	3.20	2.17	3.17	3.50	2.17	3.29	3.50	2.17	3.29	3.81
DRA	0.11	0.03	0.02	0.13	0.03	0.01	0.11	0.03	0.01	0.12	0.02	0.01
CWS	0.08	0.39	-0.45	-0.03	0.53	-0.90	0.17	0.03	-0.41	0.03	0.20	-0.73
CET	2.14	3.53	2.73	2.01	3.67	2.59	2.23	3.29	3.08	2.08	3.47	3.07
Exp. 3												
days	19	21	21	19	21	21	19	21	21	19	21	21
IRR	1.09	1.65	3.05	1.09	1.65	3.05	1.01	1.65	2.74	1.09	1.65	3.05
DRA	0.06	-0.05	0.03	0.06	0.05	0.04	0.10	0.12	0.10	0.07	0.05	0.05
CWS	0.23	0.88	-1.14	-0.91	0.42	0.12	-0.47	-0.21	0.23	-0.02	0.38	0.35
CET	1.26	2.48	1.88	0.12	2.02	3.13	0.44	1.32	2.87	1.00	1.98	3.35
Exp. 4												
days	19	21	21	19	21	21	19	21	21	19	21	21
IRR	2.29	1.46	2.50	2.16	1.46	2.50	2.16	1.46	2.65	2.16	1.76	2.71
DRA	0.09	0.02	0.01	0.09	0.03	0.01	0.10	0.04	0.01	0.08	0.02	0.01
CWS	0.18	-0.18	-0.88	0.31	-0.06	-0.68	0.20	-0.08	-0.54	0.27	-0.19	-0.34
CET	2.38	1.26	1.61	2.38	1.37	1.81	2.26	1.34	2.10	2.35	1.55	2.36

* each period amountes approx. 20 days

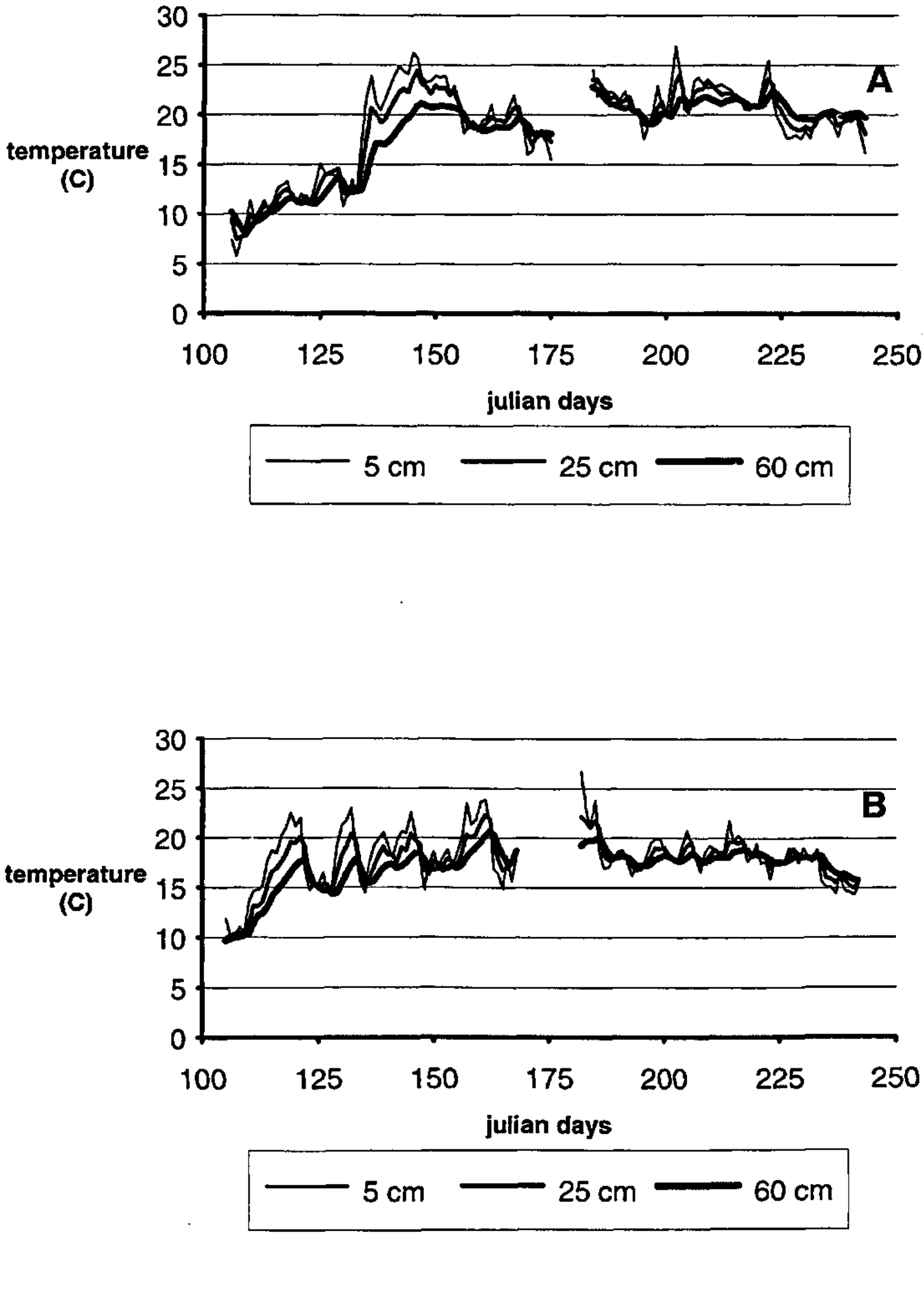


Figure 1. Average daily soil temperature (°C) at a depth of 5, 25 and 60 cm in 1992 (A: Experiments 1 and 2) and 1993 (B: Experiments 3 and 4)

3.2 Roots

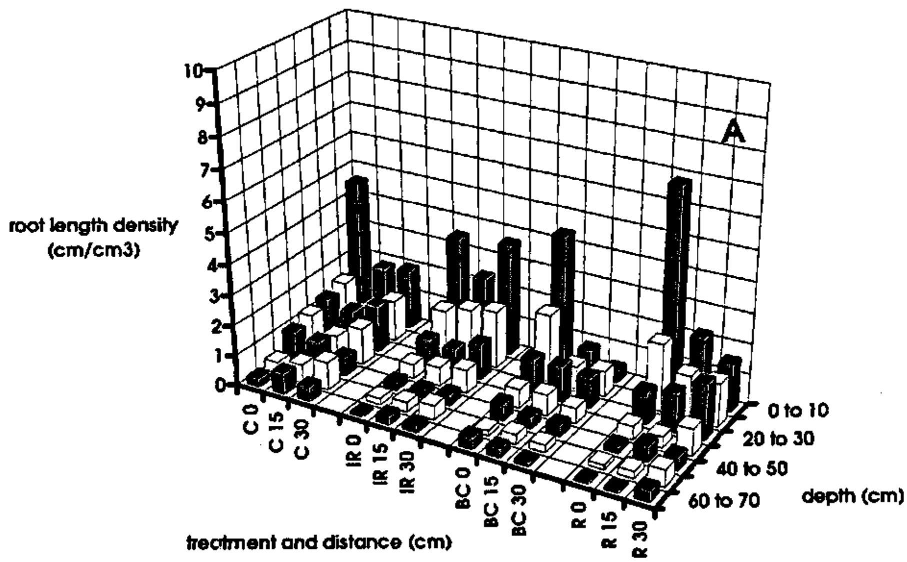
3.2.1 Core samplings

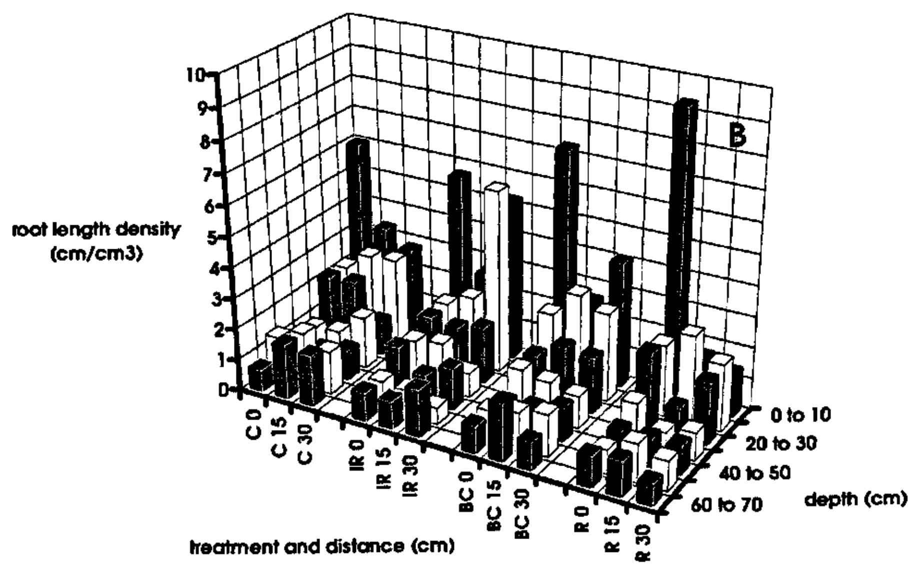
Root density as calculated from core samplings 9 weeks after planting (Appendix 3), showed steep gradients in the horizontal plane (Figure 2). In the upper 10 cm layer, root length density decreased on average from 4.8 cm per cm^3 under the row to 1.6 cm per cm^3 between the rows. In all four experiments, gradients were weaker for the IR-treatment (fertilizer placed between the rows) than for the BC-treatment (broadcast fertilizer) and the R-treatment (fertilizer placed next to the row). Horizontal gradients weakened with depth.

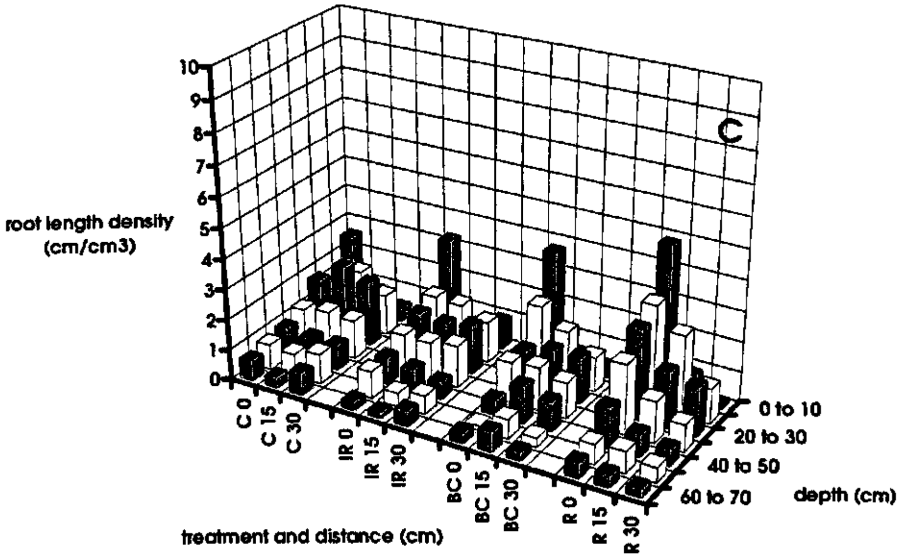
In the vertical plane, root length density decreased with depth from an average value of 2.0 cm per cm^3 for the 10-20 cm layer to 1.6, 1.0, 0.7, 0.7 and 0.6 cm per cm^3 for the 20-30, 30-40, 40-50, 50-60 and 60-70 cm layers, respectively.

3.2.2 Conversion coefficient

In order to calculate the coefficient for the conversion of the number of root intersections with the minirhizotron walls (n) into root length density (Lrv), root length density data from core samplings and root intersections from corresponding positions and time, were subjected to linear regression analysis. Variance accounted for (VAF) was only slightly affected if the multiple regression model was extended with a lateral distance factor. Extension of the model with a depth factor improved the model hardly, except for Experiment 2. As no obvious trend could be detected between the value of the conversion coefficient and distance or depth, identical coefficients were used for all depths and all lateral distances. Coefficient values (Lrv/n) amounted to 1.13, 1.76, 0.99 and 1.21 for the Experiments 1, 2, 3, and 4, respectively (Table 8).


A
root length density (cm/cm3)
10
9
8
7
6
5
4
3
2
1
0
C 0
C 15
C 30
IR 0
IR 15
IR 30
BC 0
BC 15
BC 30
R 0
R 15
R 30
treatment and distance (cm)
0 to 10
20 to 30
40 to 50
60 to 70
depth (cm)


B
root length density (cm/cm3)
10
9
8
7
6
5
4
3
2
1
0
C 0
C 15
C 30
IR 0
IR 15
IR 30
BC 0
BC 15
BC 30
R 0
R 15
R 30
treatment and distance (cm)
0 to 10
20 to 30
40 to 50
60 to 70
depth (cm)



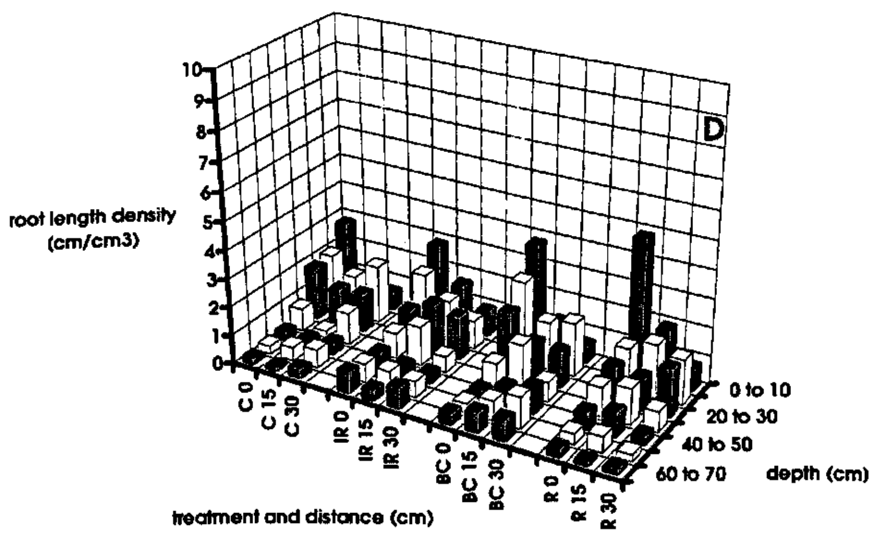


Figure 2. Root density of maize as observed in core samples 9 weeks after planting as related to the N application method, (c = control, ir = inter row, bc = broadcast, r = next to row), depth and lateral distance from the plant, for Experiment 1 (a), Experiment 2 (b), Experiment 3 (c) and Experiment 4 (d)

Table 8. Coefficient to convert root intensities (cm^{-2}) into root length densities ($cm\ cm^{-3}$)

	accounting for lateral distance	none	accounting for depth						VAF+
			5	10	15	20	30	45+60	
Exp. 1	none	1.13***							48
	none		1.07***	1.30***	0.96***	1.83***	1.59***	1.05*	50
	0	1.10***							47
	15	1.22***							
	30	1.19***							
	0		1.03***	1.24***	1.12***	1.87***	3.29**	2.07	45
	15		1.07***	1.33***	1.34***	1.65***	1.20**	2.32	
	30		1.39***	1.97***	0.73***	1.99***	1.70**	0.81	
Exp. 2	none	1.76***							16
	none		2.18***	2.24***	1.37***	1.44***	1.23***	1.45**	26
	0	1.84***							14
	15	1.67***							
	30	1.67***							
	0		2.08***	2.59***	1.21***	1.24***	1.18**	1.37	28
	15		2.13***	1.68***	1.86***	1.44***	1.34**	1.46*	
	30		5.83***	2.48***	1.26***	1.74***	1.19*	1.56	
Exp. 3	none	0.99***							11
	none		1.14***	0.99***	1.22***	0.82***	0.90***	1.29**	11
	0	1.08***							15
	15	0.99***							
	30	0.72***							
	0		1.13***	1.01***	1.11***	0.98***	1.41***	1.28NS	3
	15		1.77NS	0.89**	1.69**	0.84***	0.83***	1.15NS	
	30		2.57NS	1.43***	1.33***	0.60*	0.72*	1.94NS	
Exp. 4	none	1.21***							29
	none		1.09***	1.45***	1.42***	1.14***	1.10***	0.99**	30
	0	1.22***							33
	15	1.51***							
	30	0.95***							
	0		1.10***	1.40***	1.28***	1.50***	1.46***	0.83NS	35
	15		1.51***	2.60***	1.79***	1.97***	1.04***	0.99NS	
	30		0.61*	1.08**	1.66***	0.80***	0.95***	1.82NS	

\+ VAF = fraction of the variance accounted for

* ($P<0.10$), ** ($P<0.05$), *** ($P<0.01$)

3.2.3 Minirhizotron observations

The number of root intersections with the lateral or bottom side of the minirhizotron wall, hardly differed from the number of intersections with the upper side, according to measurements made at the end of Experiments 3 and 4. Numbers of intersections with the bottom side tended to be somewhat smaller, however, in deeper soil layers (Table 9). The usual observation from the upper side were therefore considered representative and not adjusted prior to further analysis. Root intensity observations (n, number of roots per cm^2 minirhizotron wall) were converted to root length densities (Lrv) according to Paragraph 3.2.2 and allocated to one of 35 soil compartments (viz. 5 lateral distance classes x 7 depth classes; Appendix 4). Subsequently, data from the four experiments were pooled per treatment by plotting observed root length densities against thermal time for each of the 35 soil compartments.

C-values within a lateral distance class were kept contstant as VAF was not improved by allowing c to change with depth.

Calculated values for l, c and VAF are given in Table 10 for each lateral distance class and treatment. Thus, vertical and horizontal gradients were calculated in agreement with the observations from core samples. Again, horizontal gradients were weakest in the deeper soil layers, strongest for the R-treatment and weakest for the control and the IR-treatment. This is illustrated for two depths at 400 and at 600 day degrees after emergence (DDAE) (Figure 3).

Table 9. Average numbers of roots (cm-2) along the upper, lateral right and left, and bottom side of a minirhizotron

date	layer (cm)	side			
		upper	right	left	bottom
14-6-93	0-25	1.4	1.6	1.5	1.4
	25-70	0.7	1.0	0.8	0.5
31-8-93	0-25	1.2	1.4	1.3	1.5
	25-70	0.7	0.6	0.6	0.3

Table 10A. Time lag (l, °Cd) and ratio (c, cm per (°Cd * cm³)) and variance accounted for (VAF, %) for the soil compartment specific relationship between heatsum (°Cd after emergence, > 8 °C) and root length density for control

distance (cm)	depth (cm)	l	c x 1000	VAF
0 to 4	5	0	5.144	67
	10	108	5.144	
	15	248	5.144	
	20	323	5.144	
	30	281	5.144	
	45	403	5.144	
	60	593	5.144	
4 to 11	5	3	4.283	76
	10	44	4.283	
	15	179	4.283	
	20	223	4.283	
	30	390	4.283	
	45	452	4.283	
	60	507	4.283	
11to 19	5	219	4.193	65
	10	176	4.193	
	15	271	4.193	
	20	274	4.193	
	30	275	4.193	
	45	419	4.193	
	60	418	4.193	
19 to 26	5	343	4.140	41
	10	119	4.140	
	15	310	4.140	
	20	293	4.140	
	30	297	4.140	
	45	435	4.140	
	60	434	4.140	
26 to 30	5	338	3.704	42
	10	211	3.704	
	15	87	3.704	
	20	248	3.704	
	30	343	3.704	
	45	350	3.704	
	60	427	3.704	

Table 10B. Time lag (l, °Cd) and ratio (c, cm per (°Cd * cm³)) and variance accounted for (VAF, %) for the soil compartment specific relationship between heatsum (°Cd after emergence, > 8 °C) and root length density for N-application between the rows

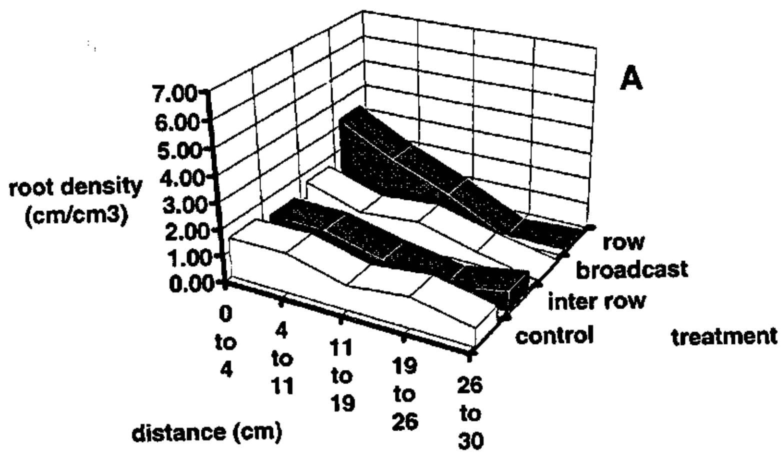
distance (cm)	depth (cm)	l	c x 1000	VAF
0 to 4	5	0	4.613	79
	10	82	4.613	
	15	148	4.613	
	20	199	4.613	
	30	331	4.613	
	45	467	4.613	
	60	500	4.613	
4 to 11	5	88	3.596	74
	10	45	3.596	
	15	76	3.596	
	20	238	3.596	
	30	195	3.596	
	45	364	3.596	
	60	466	3.596	
11 to 19	5	187	3.540	67
	10	195	3.540	
	15	77	3.540	
	20	240	3.540	
	30	218	3.540	
	45	426	3.540	
	60	403	3.540	
19 to 26	5	177	2.816	62
	10	271	2.816	
	15	69	2.816	
	20	172	2.816	
	30	287	2.816	
	45	722	2.816	
	60	487	2.816	
26 to 30	5	256	4.731	61
	10	235	4.731	
	15	175	4.731	
	20	123	4.731	
	30	360	4.731	
	45	722	4.731	
	60	724	4.731	

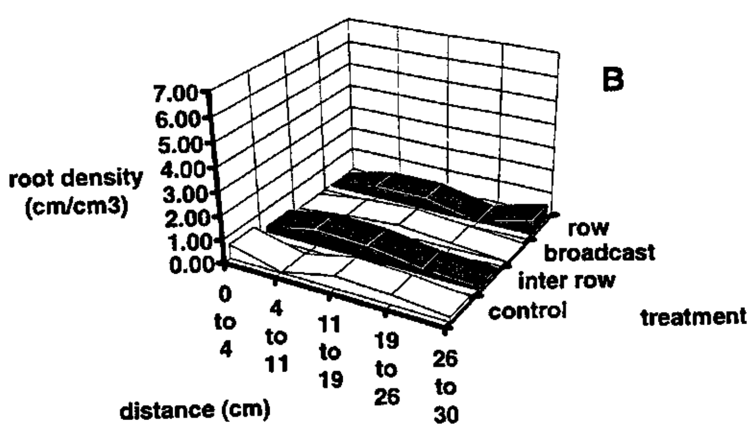
Table 10C. Time lag (l, °Cd) and ratio (c, cm per (°Cd ⋆ cm³)) and variance accounted for (VAF, %) for the soil compartment specific relationship between heatsum (°Cd after emergence, > 8 °C) and root length density for broadcast N-application

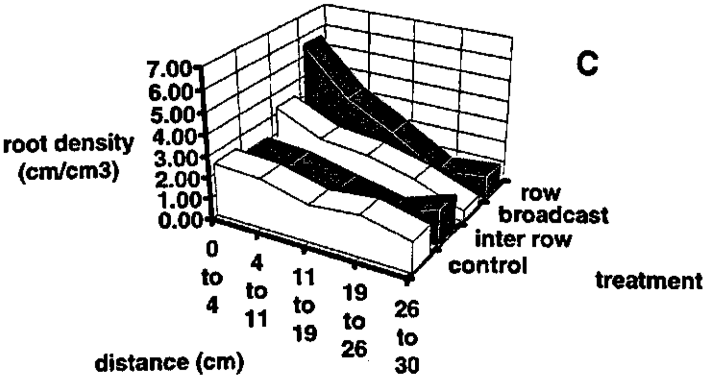
distance (cm)	depth (cm)	l	c x 1000	VAF
0 to 4	5	0	8.380	74
	10	207	8.380	
	15	262	8.380	
	20	383	8.380	
	30	442	8.380	
	45	667	8.380	
	60	570	8.380	
4 to 11	5	3	6.800	72
	10	266	6.800	
	15	215	6.800	
	20	338	6.800	
	30	361	6.800	
	45	483	6.800	
	60	513	6.800	
11 to 19	5	188	4.641	60
	10	166	4.641	
	15	186	4.641	
	20	208	4.641	
	30	311	4.641	
	45	443	4.641	
	60	503	4.641	
19 to 26	5	487	4.668	46
	10	294	4.668	
	15	187	4.668	
	20	440	4.668	
	30	351	4.668	
	45	425	4.668	
	60	667	4.668	
26 to 30	5	414	5.496	42
	10	507	5.496	
	15	189	5.496	
	20	448	5.496	
	30	472	5.496	
	45	652	5.496	
	60	722	5.496	

Table 10D. Time lag (l, °Cd) and ratio (c, cm per (°Cd * cm3)) and variance accounted for (VAF, %) for the soil compartment specific relationship between heatsum (°Cd after emergence, > 8 oC) and root length density for N-application next to the row

distance (cm)	depth (cm)	l	c x 1000	VAF
0 to 4	5	0	11.601	87
	10	116	11.601	
	15	365	11.601	
	20	394	11.601	
	30	497	11.601	
	45	512	11.601	
	60	520	11.601	
4 to 11	5	0	6.470	75
	10	77	6.470	
	15	206	6.470	
	20	240	6.470	
	30	315	6.470	
	45	435	6.470	
	60	490	6.470	
11to 19	5	158	5.139	60
	10	177	5.139	
	15	227	5.139	
	20	174	5.139	
	30	290	5.139	
	45	380	5.139	
	60	448	5.139	
19 to 26	5	269	5.624	61
	10	452	5.624	
	15	154	5.624	
	20	275	5.624	
	30	389	5.624	
	45	439	5.624	
	60	447	5.624	
26 to 30	5	425	4.893	42
	10	378	4.893	
	15	116	4.893	
	20	198	4.893	
	30	261	4.893	
	45	410	4.893	
	60	445	4.893	


A
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
root density
(cm/cm3)
0 to 4
4 to 11
11 to 19
19 to 26
26 to 30
distance (cm)
row
broadcast
inter row
control
treatment


B
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
root density
(cm/cm3)
0 to 4
4 to 11
11 to 19
19 to 26
26 to 30
distance (cm)
row
broadcast
inter row
control
treatment



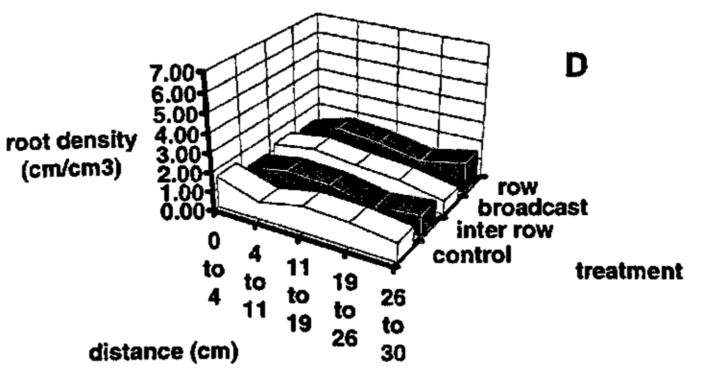
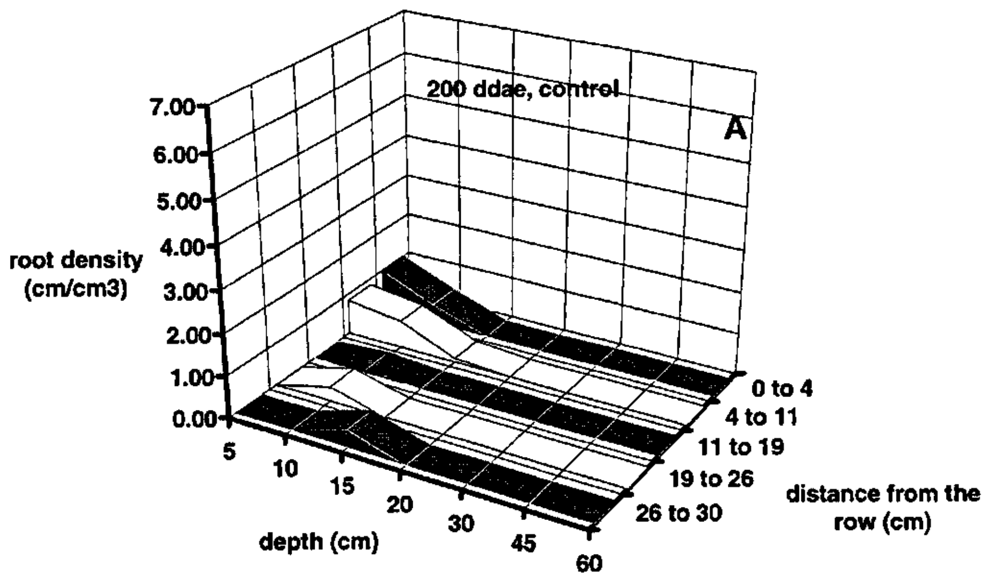
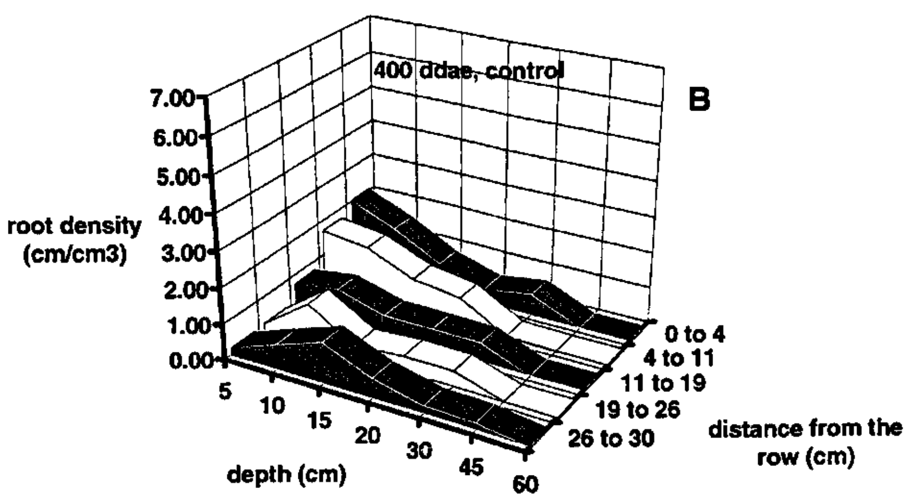
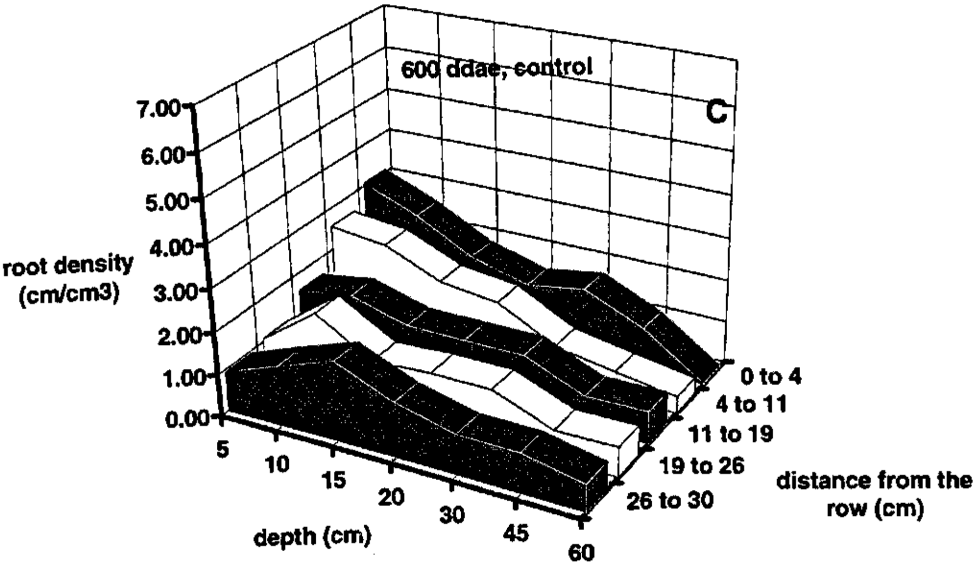
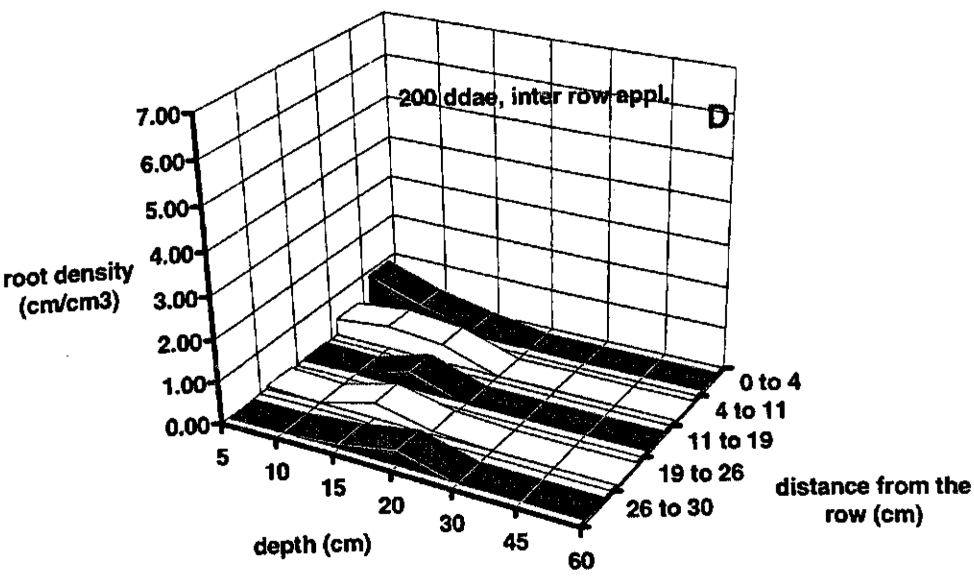


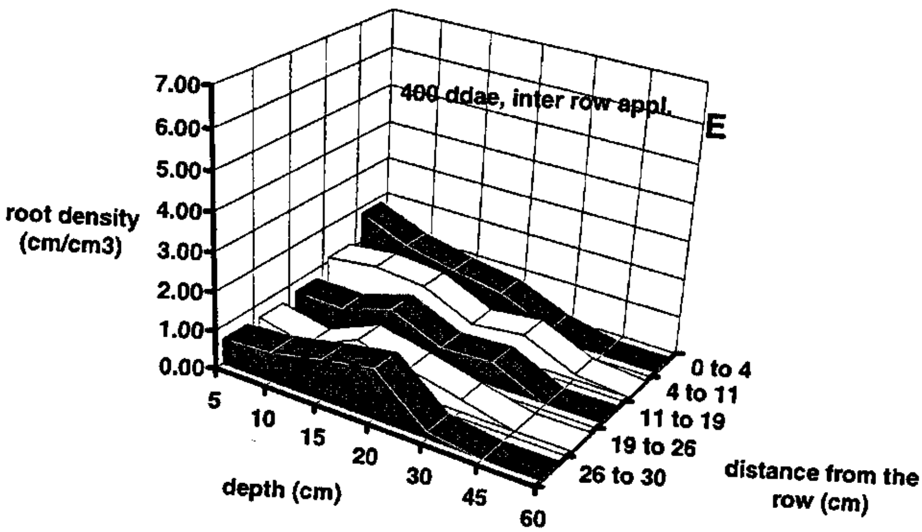
Figure 3. Calculated root length density of maize at 400 day degrees after emergence (DDAE) and 10 cm depth (A), 400 DDAE and 30 cm depth (B), 600 DDAE and 10 cm depth (C) and 600 DDAE and 30 cm depth as related to the N application method and lateral distance from the plant.


200 ddae, control
A
root density (cm/cm3)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
5
10
15
20
30
45
60
depth (cm)
0 to 4
4 to 11
11 to 19
19 to 26
26 to 30
distance from the row (cm)

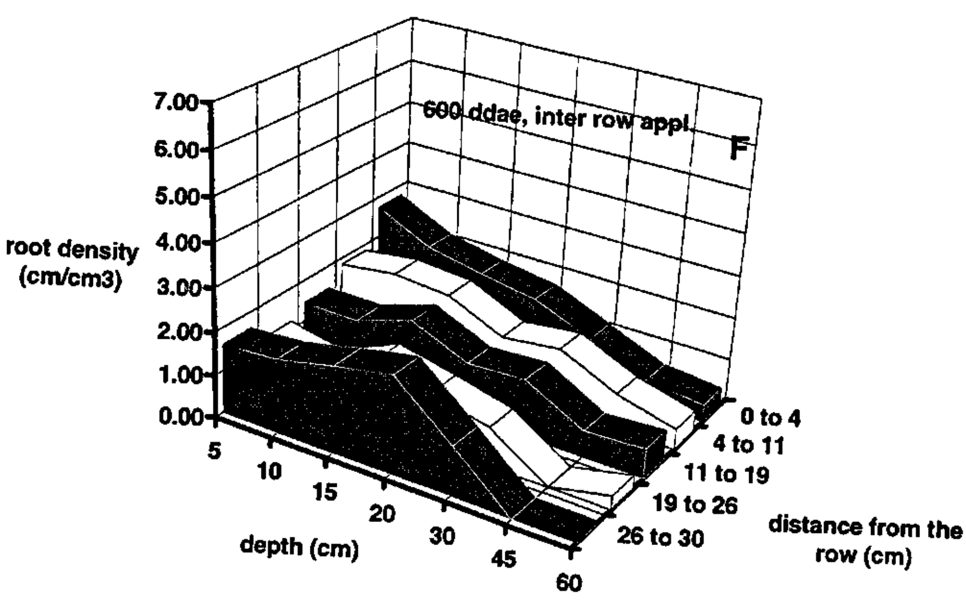

400 ddae, control
B
root density (cm/cm3)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
5
10
15
20
30
45
60
depth (cm)
0 to 4
4 to 11
11 to 19
19 to 26
26 to 30
distance from the row (cm)


600 ddae, control
C
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
root density (cm/cm3)
5
10
15
20
30
45
60
depth (cm)
0 to 4
4 to 11
11 to 19
19 to 26
26 to 30
distance from the row (cm)

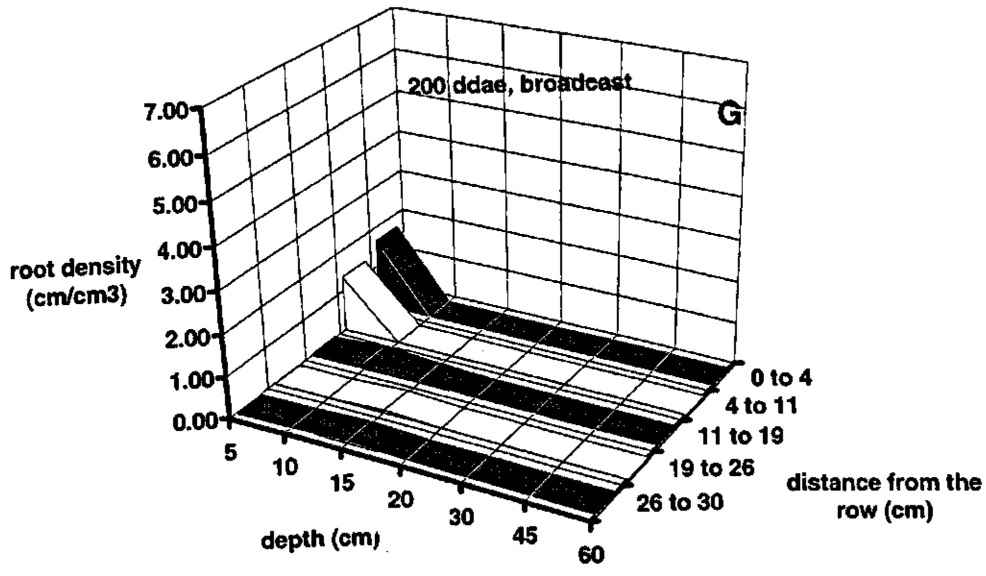

200 ddae, inter row appl.
D
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
root density (cm/cm3)
5
10
15
20
30
45
60
depth (cm)
0 to 4
4 to 11
11 to 19
19 to 26
26 to 30
distance from the row (cm)

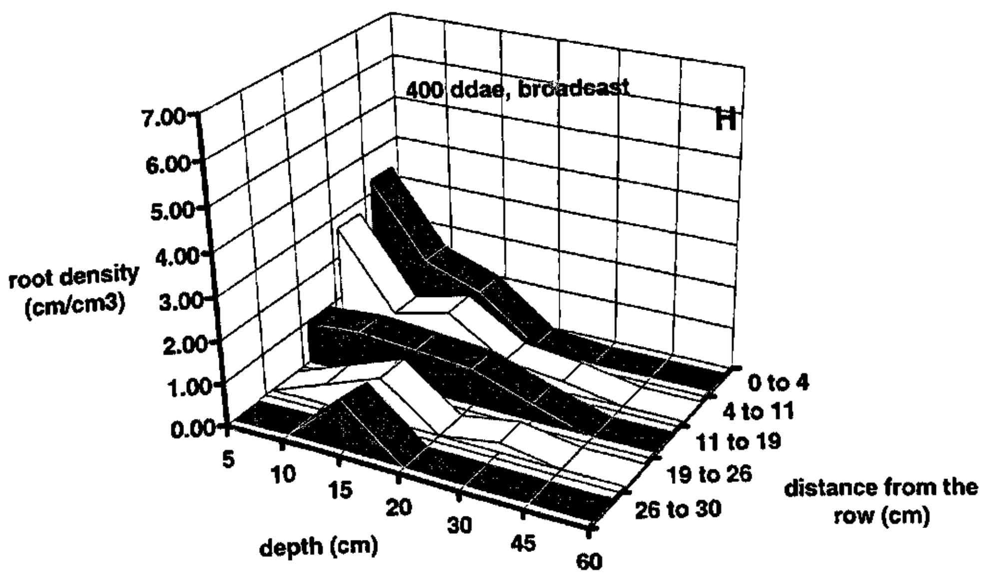


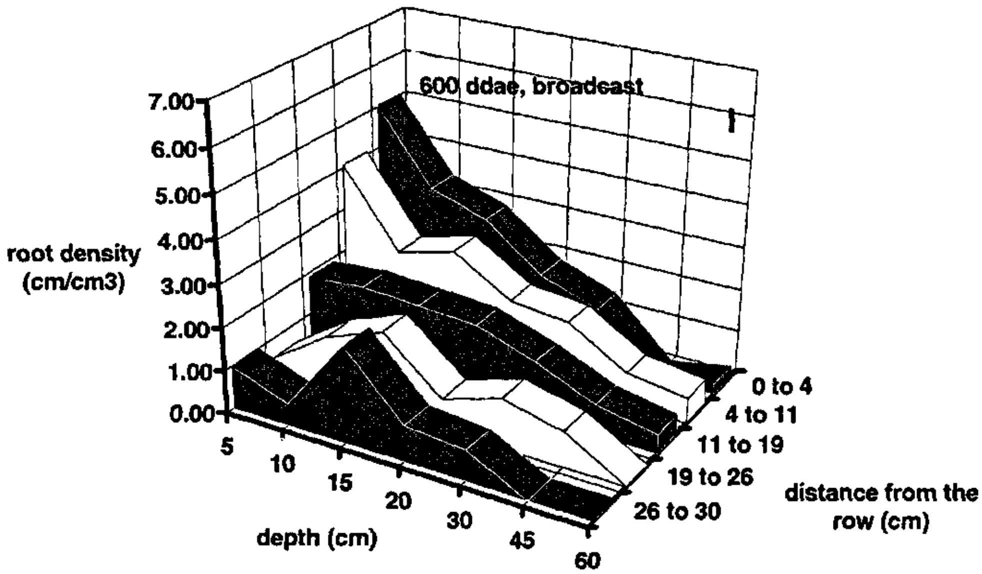
400 ddae, inter row appl.
E
root density (cm/cm3)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
5
10
15
20
30
45
60
depth (cm)
0 to 4
4 to 11
11 to 19
19 to 26
26 to 30
distance from the row (cm)

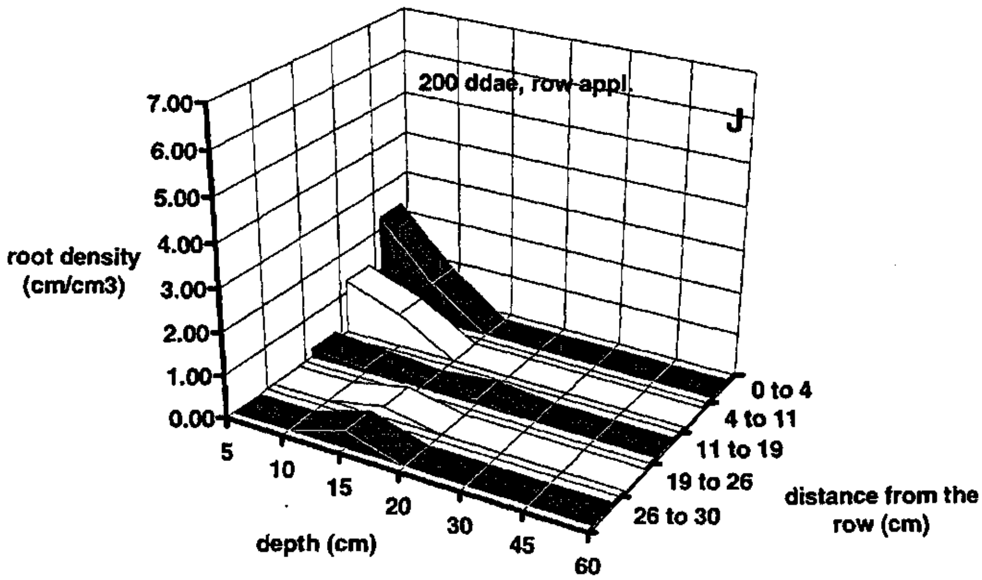


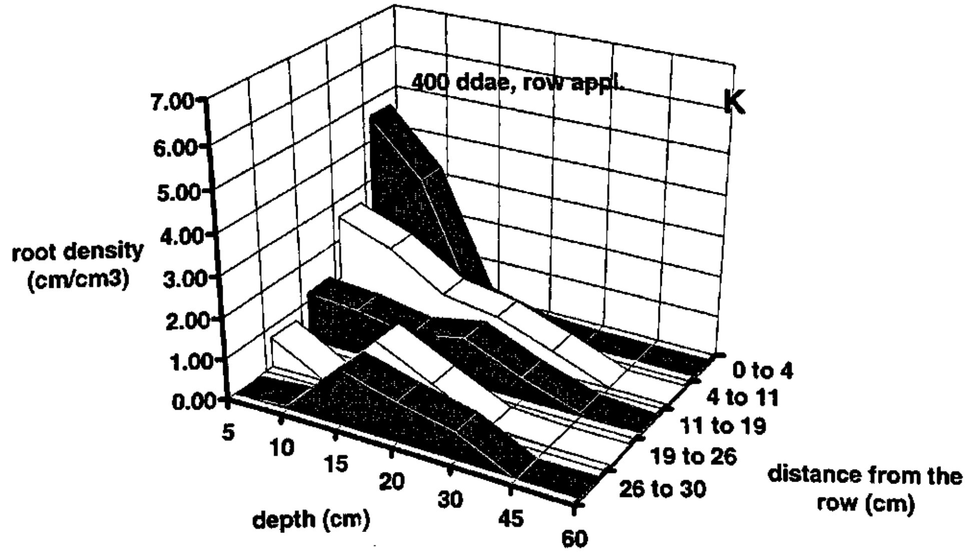
600 ddae, inter row appl.
F
root density (cm/cm3)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
5
10
15
20
30
45
60
depth (cm)
0 to 4
4 to 11
11 to 19
19 to 26
26 to 30
distance from the row (cm)


200 ddae, broadcast
G
root density (cm/cm3)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
5
10
15
20
30
45
60
depth (cm)
0 to 4
4 to 11
11 to 19
19 to 26
26 to 30
distance from the row (cm)


400 ddae, broadcast
H
root density (cm/cm3)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
5
10
15
20
30
45
60
depth (cm)
0 to 4
4 to 11
11 to 19
19 to 26
26 to 30
distance from the row (cm)


600 ddae, broadcast
I
root density
(cm/cm3)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
5
10
15
20
30
45
60
depth (cm)
0 to 4
4 to 11
11 to 19
19 to 26
26 to 30
distance from the
row (cm)


200 ddae, row-appl.
J
root density
(cm/cm3)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
5
10
15
20
30
45
60
depth (cm)
0 to 4
4 to 11
11 to 19
19 to 26
26 to 30
distance from the
row (cm)



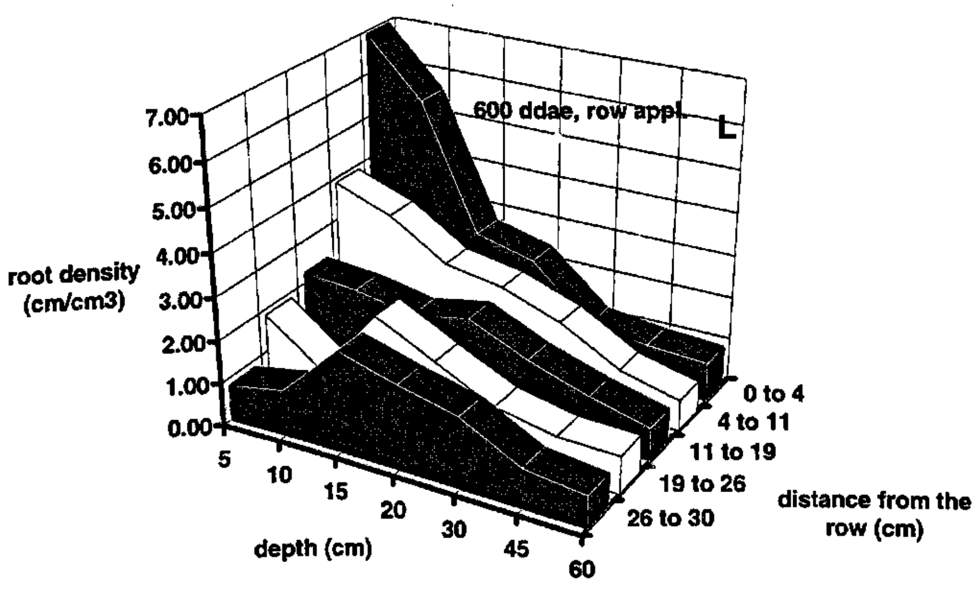


Figure 4. Calculated root length density of maize for the control (A-C), inter row applied N (D-F), broadcast N (G-I) and row applied N (J-L) at 200, 400 and 600 day degrees after emergence as related to the depth and lateral distance from the plant

Figure 4 shows the root extension at three moments in time for the 35 soil compartments for each treatment. They illustrate that after 200 DDAE some roots have arrived in the soil volume between the rows, be it at a depth around 15 cm only. No roots can be found below a depth of 20 cm at that stage except for the treatment where N was placed in between the rows. Roots are present in only 20-43 percent of the 35 compartments at that stage. After 400 DDAE the upper 10 cm between the rows is still unexploited in the BC- and R-treatment. No roots can be found below a depth of 45 cm at that stage. Roots are present in 51-74 percent of the compartments at that stage. After 600 DDAE more than 90 percent of the soil compartments are exploited by roots. Generally, however, root length densities below a depth of 45 cm and in the upper 10 cm between the rows (except for the IR treatment), do not exceed 1 cm per cm^3.

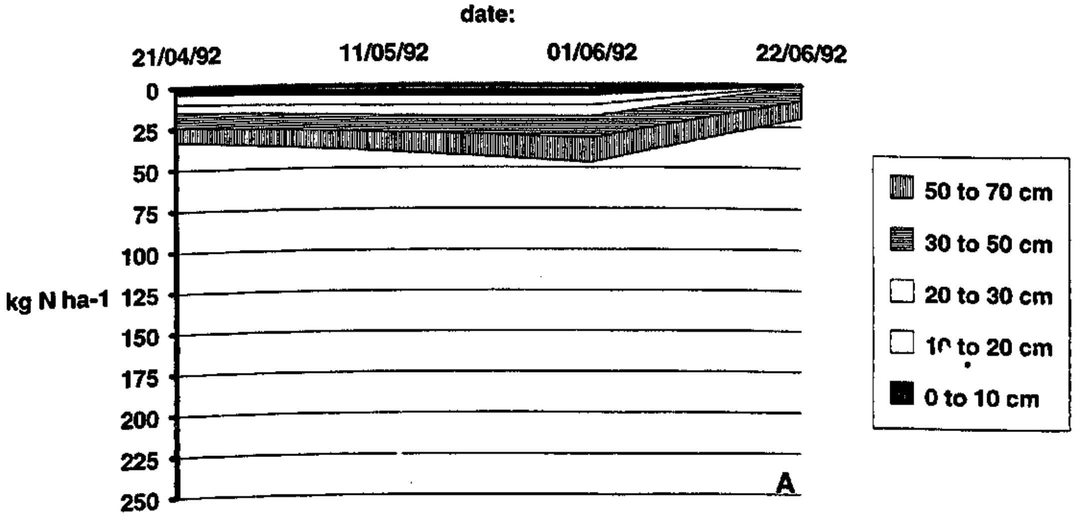
3.3 Soil mineral nitrogen

Soil mineral nitrogen (SMN) supply in the upper 70 cm layer of the control treatments at the start of Experiments 1, 2, 3 and 4 amounted to 32, 142, 138 and 184 kg per ha, respectively. In all four experiments the SMN supply remained more or less constant during the first 2-4 weeks indicating that N-uptake by the crop and net mineralization were in balance. After that period, uptake exceeded net mineralization so that SMN supplies were gradually depleted starting with the upper layers (Figure 5). Numerical values of the SMN supply are given in Appendix 5.

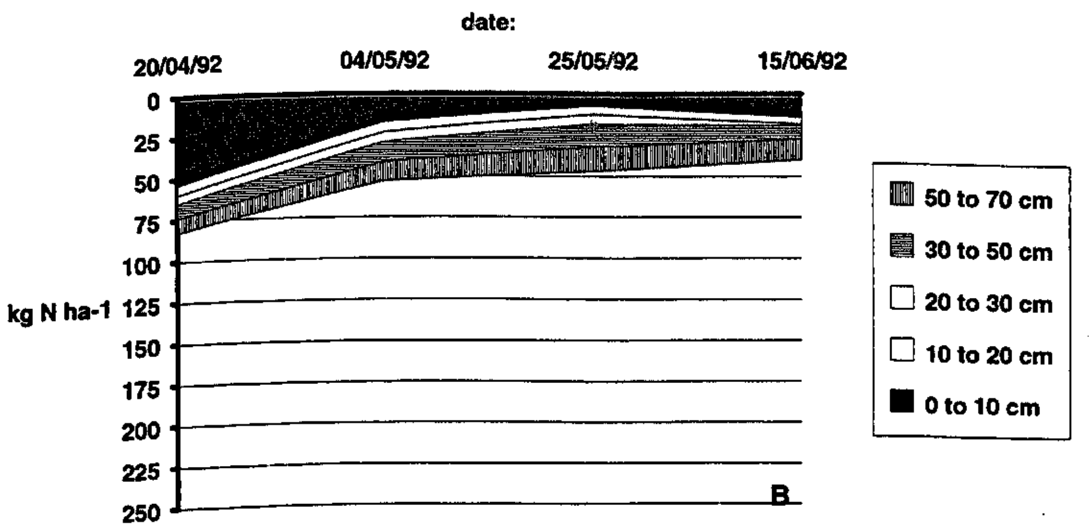
Depletion showed a distinct pattern in the horizontal plane as well. In the control treatment no difference was observed between the SMN supply below the row and between the rows at the first (pre-emergence) and second (7-14 days after emergence) sampling date. SMN supplies on the third (28-35 days after emergence) and fourth (49-56 days after emergence) suggested, however, that SMN was preferably taken up from the soil volume below the row (Figure 6).

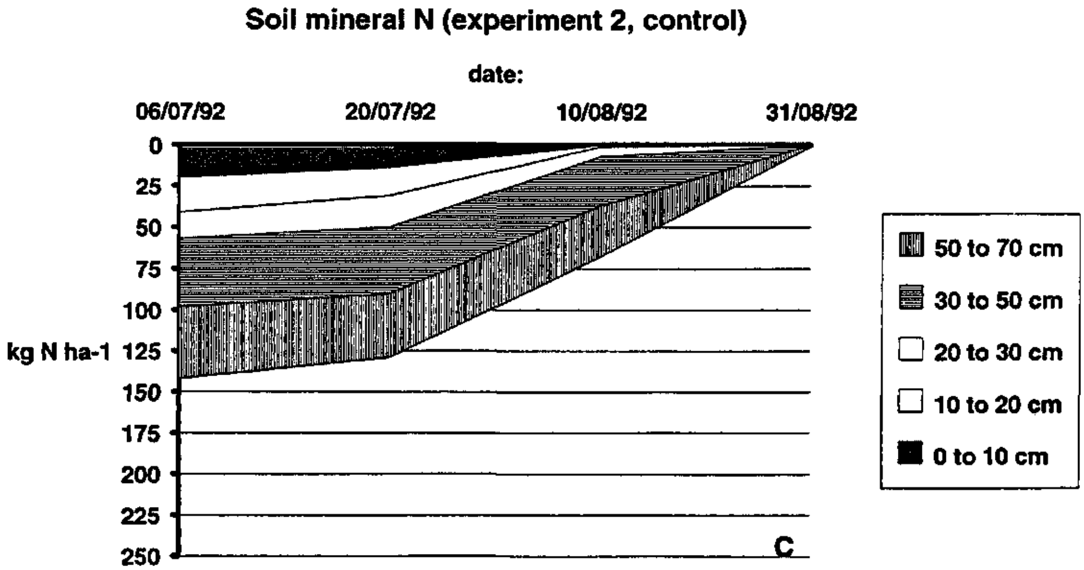
As for the BC-treatment SMN supply in all four experiments was greater under the row than between the rows for unexplained reasons (Appendix 5). This gradient was still visible at the second sampling date, fainted at the third sampling date and was even converted at the fourth sampling date. Again, this suggests that SMN was somewhat stronger taken up from the soil volume below the row (Figure 7).

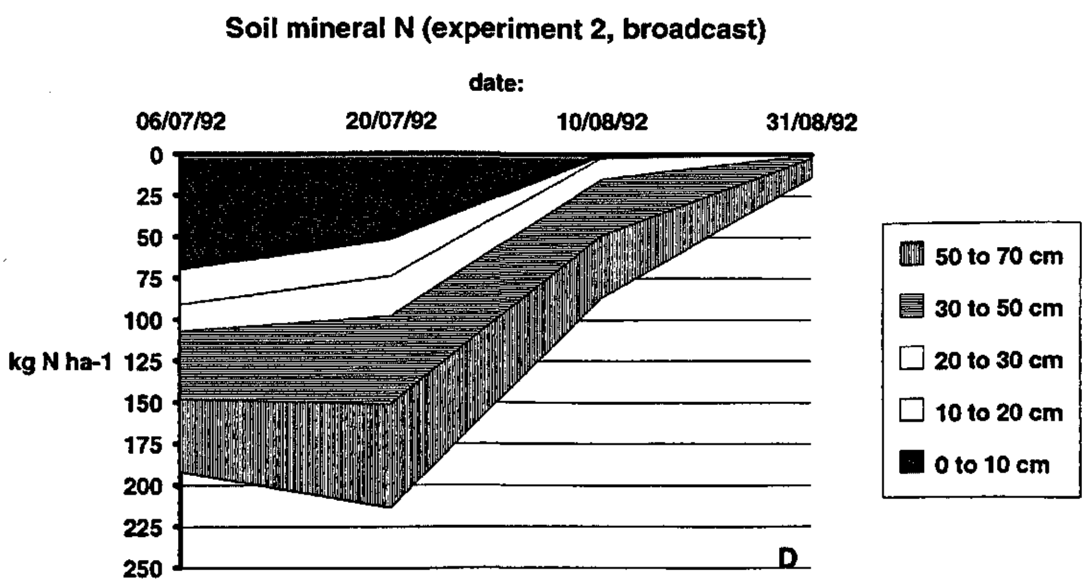
Soil mineral N (experiment 1, control)

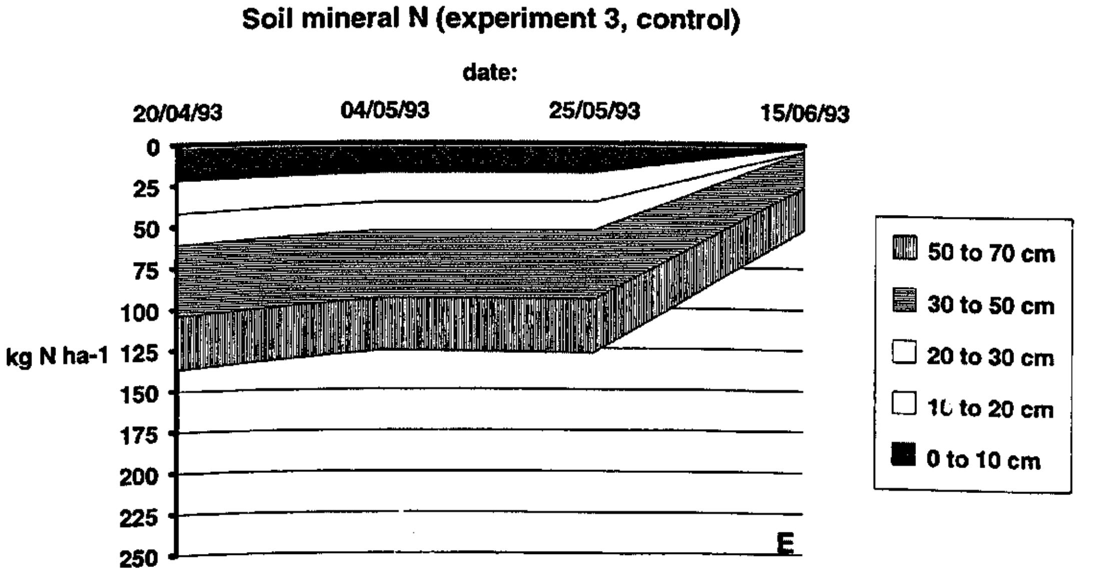


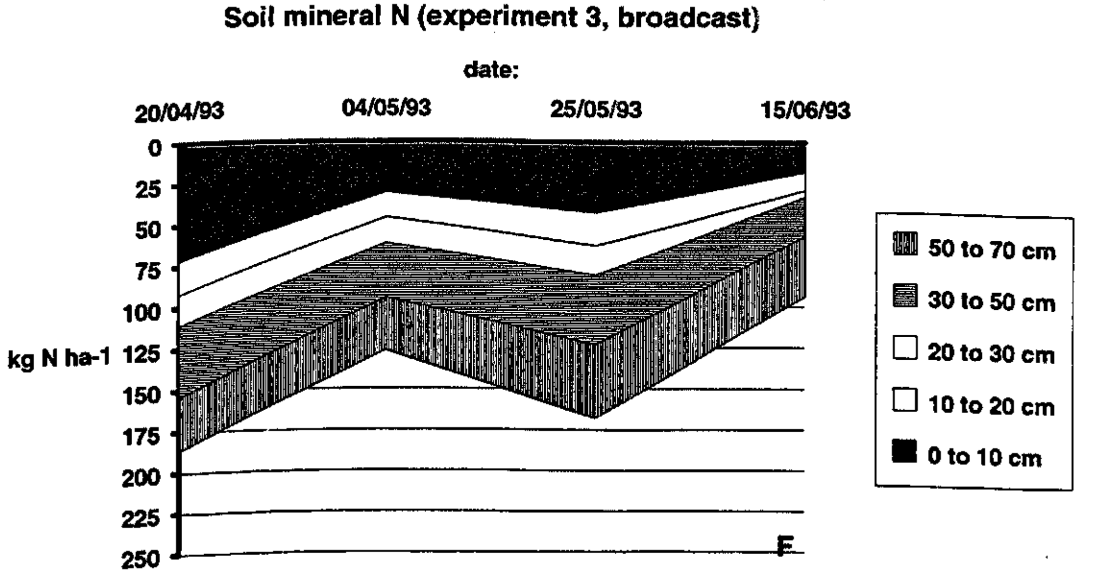
Soil mineral N (experiment 1, broadcast)

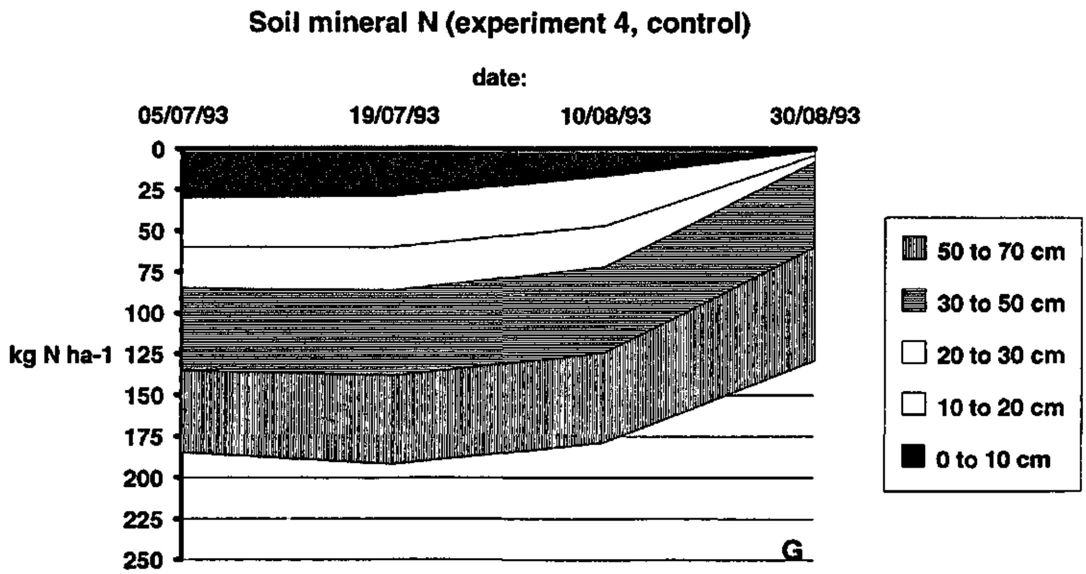



Soil mineral N (experiment 2, control)
date:
06/07/92
20/07/92
10/08/92
31/08/92
0
25
50
75
100
kg N ha-1 125
150
175
200
225
250
C
50 to 70 cm
30 to 50 cm
20 to 30 cm
10 to 20 cm
0 to 10 cm


Soil mineral N (experiment 2, broadcast)
date:
06/07/92
20/07/92
10/08/92
31/08/92
0
25
50
75
100
kg N ha-1 125
150
175
200
225
250
D
50 to 70 cm
30 to 50 cm
20 to 30 cm
10 to 20 cm
0 to 10 cm


Soil mineral N (experiment 3, control)
date:
20/04/93
04/05/93
25/05/93
15/06/93
0
25
50
75
100
125
150
175
200
225
250
kg N ha-1
50 to 70 cm
30 to 50 cm
20 to 30 cm
10 to 20 cm
0 to 10 cm
E


Soil mineral N (experiment 3, broadcast)
date:
20/04/93
04/05/93
25/05/93
15/06/93
0
25
50
75
100
125
150
175
200
225
250
kg N ha-1
50 to 70 cm
30 to 50 cm
20 to 30 cm
10 to 20 cm
0 to 10 cm
F



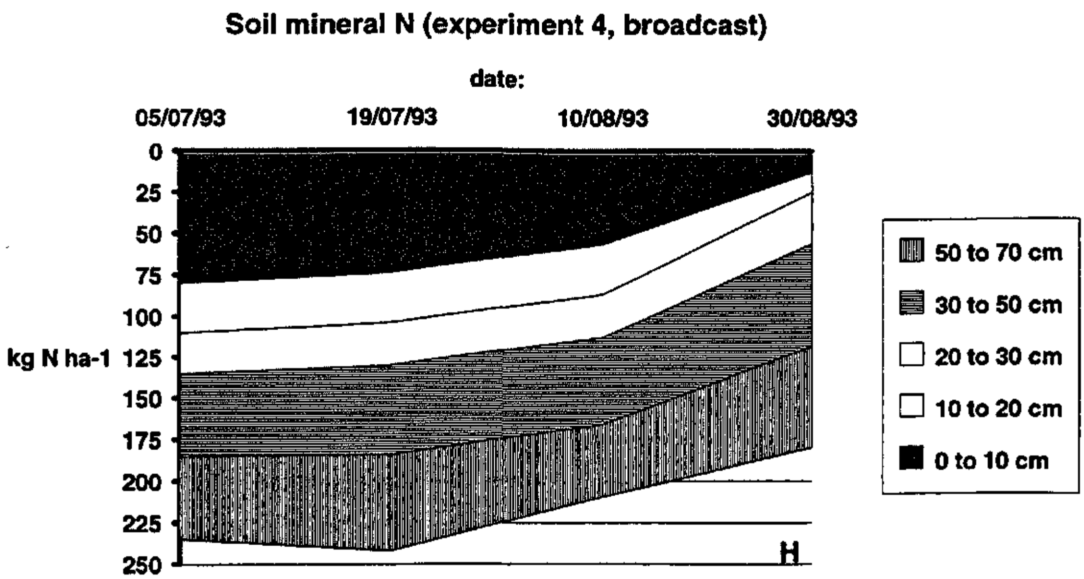
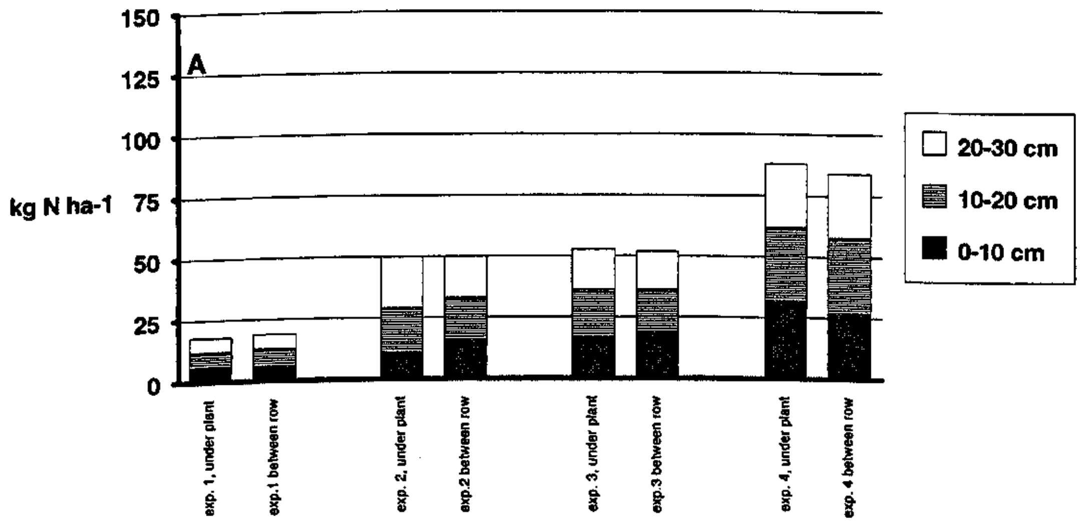
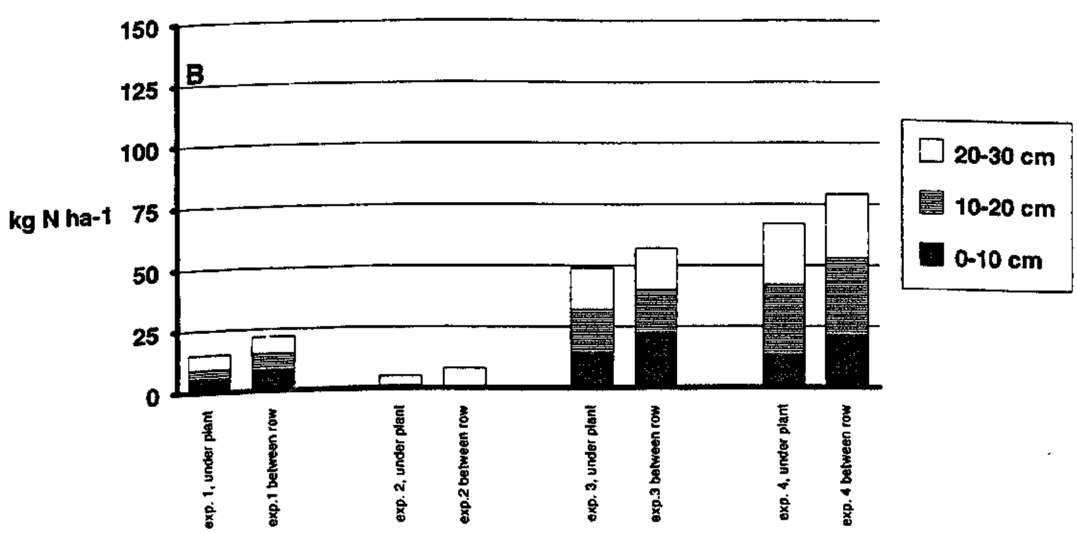


Figure 5. Soil mineral N supply of the control and broadcast N application in Experiment 1 (A, B), Experiment 2 (C, D), Experiment 3 (E, F) and Experiment 4 (G, H) as related to time

Soil mineral N as related to lateral position (control, 2nd sampling date)



Soil mineral N as related to lateral position (control, 3rd sampling date)



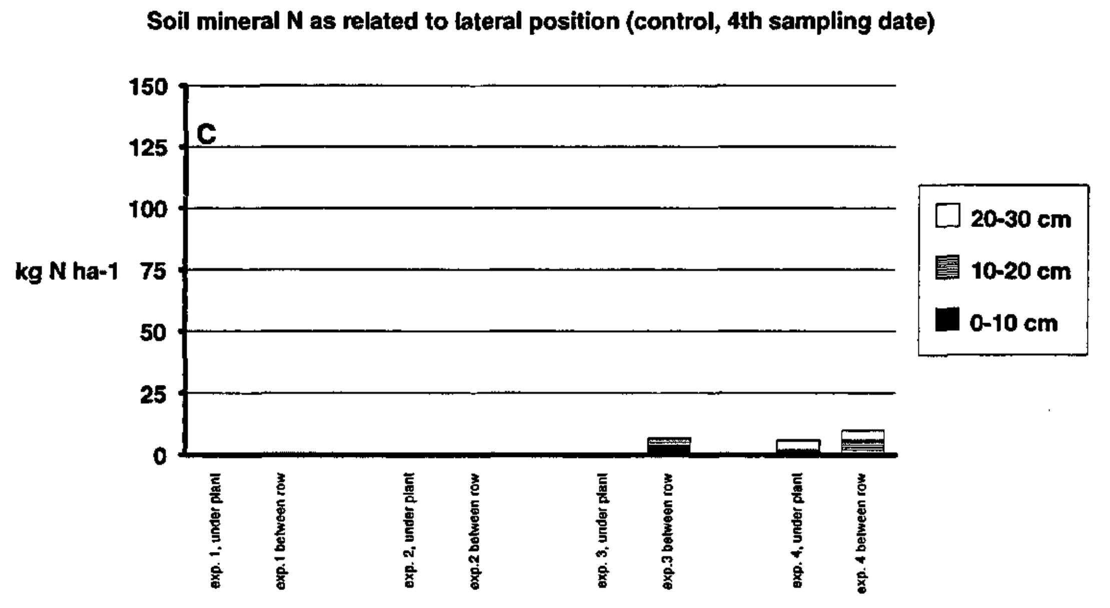
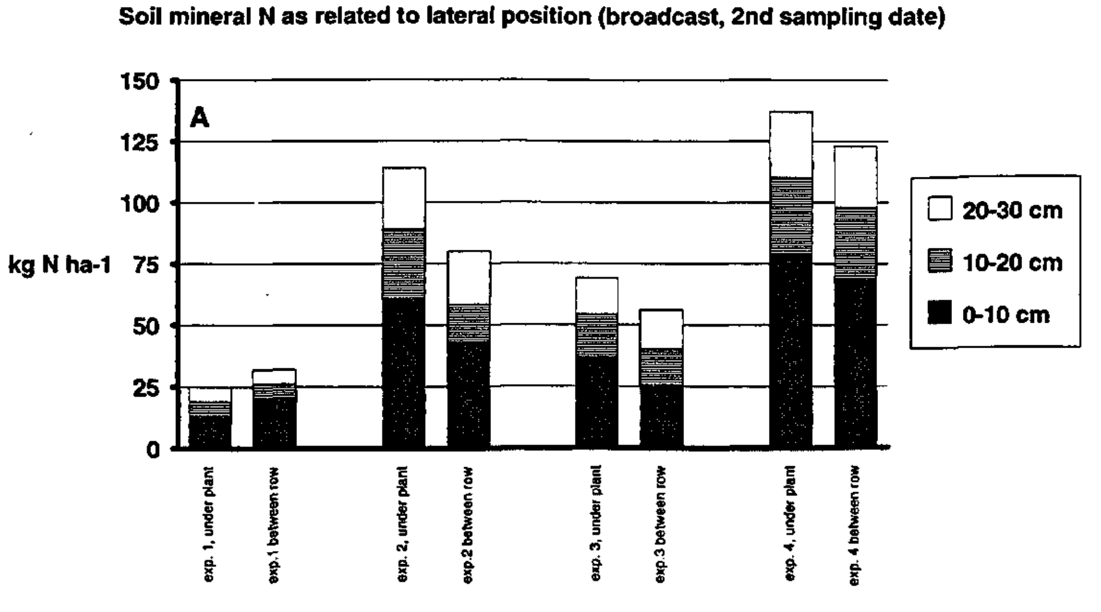
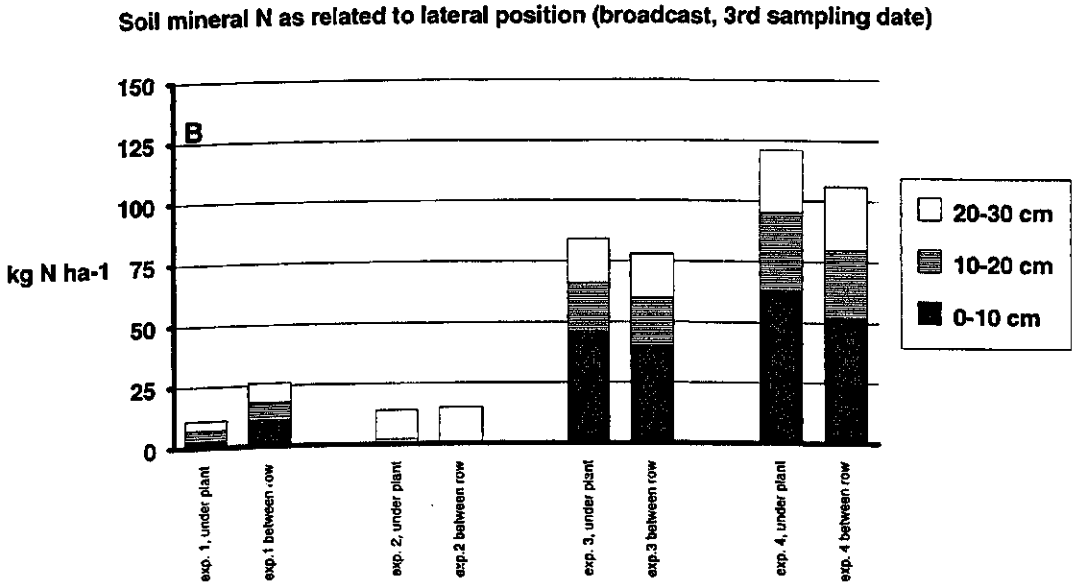


Figure 6. Soil mineral N as related to the lateral position in the control treatment (a) 7-14, (b) 28-35 and (c) 49-56 days after emergence





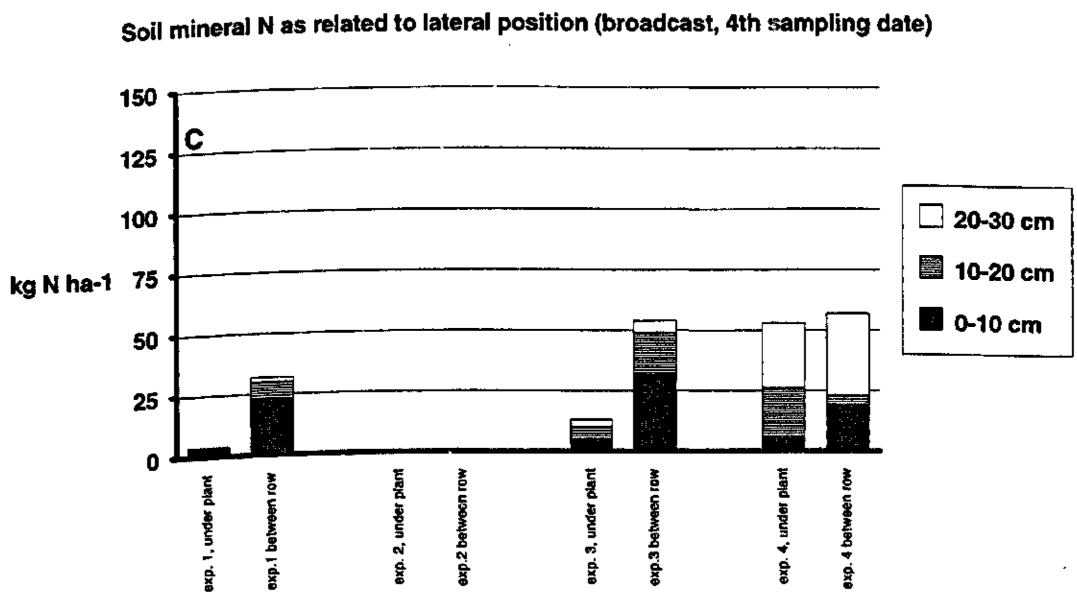


Figure 7. Soil mineral N as related to the lateral position in the broadcast treatment (a) 7-14, (b) 28-35 and (c) 49-56 days after emergence

3.4 Crop performance

3.4.1 General remarks

As temperature regimes differed among experiments, the time lag between planting and emergence varied from 3-19 days (Table 3). Expressed in thermal time, 28-67 day degrees (>8 °C) were needed for germination and emergence (Table 4). In all four experiments, harvest took place 50-56 days after emergence (Table 3). Yet, at the time of harvest, crops differed substantially in height and number of leaves (Table 11) and in yield (Table 12). Development stage and yield were positively related to temperature.

3.4.2 Chlorophyll content and leaf area

Chlorophyll contents of fertilized crops were always higher (except for Experiment 3) than those of the control. Except for Experiment 4, values were highest for the R-treatment (Table 13). Leaf area index (LAI) was generally slightly higher for fertilized crops than for the control. Within fertilizer treatments none of the application techniques was superior in terms of LAI (Table 14).

3.4.3 Dry matter yield and relative growth rate

Shoot dry matter reacted positively on N-application. The BC-treatment was inferior to the R-treatment in all four experiments and also inferior to the IR-treatment in Experiments 1, 3 and 4. The IR-treatment equalled the R-treatment in Experiments 1 and 4 (Table 12). In all four experiments, relative growth rate (RGR) was higher for the R-treatment than for the B-treatment and at least equal to the IR-treatment. The higher RGR was associated with a higher net assimilation rate in Experiments 2 and 4 and with a higher specific leaf area in Experiment 1 (Table 14).

3.4.4 Nitrogen flows

Total nitrogen (N) and nitrate-N contents of the crop reacted positively on N-application without any consistent differences between the application techniques (Table 15 and 16). N-yields were, generally, greatest for the R-treatment followed by the IR-treatment (Table 17).

Fertilizer recoveries in the crop were generally highest for the R-treatment and lowest for the BC-treatment. Except for Experiment 3, there was a great similarity between N recoveries in the crop based on the difference method and recoveries based on isotope dilution method (Table 18). Numerical values of the ^{15}N content are presented in Appendix 6.

Table 11. Phenological events

year	experiment number 1992 1	2	1993 3	4
planting	15th April	3rd July	15th April	1st July
start of emergence	3rd May			5th July
50% emergence	4th May	6th July	25th April	7th July
100% emergence	7th May	7th July	27th April	9th July
number of fully expanded leaves:				
1	14th May		4th May	13th July
3	22nd May	21st July	12th May	28th July
4	28th May	24th July	22nd May	9th August
5		31st July		
6	8th June	6th August	6th June	
7	16th June			24th August
8		12th August		30st August
height (cm):				
5	14th May			
10	18th May		12th May	13th July
15	22nd May			
20	25th May	21st July	19th May	28th July
30	1st June	27th July	24th May	9th August
40	10th June	31st July	1st June	
50		6th August		
90				30st August
harvest	23th June	31st August	15th June	30st August

Table 12. Dry matter content (DM%, g 100 g^{-1}) and dry matter yield (DMY, kg ha^{-1}) of maize circa 9 weeks after emergence

experiment number	treatment*	DM %			DMY			
		root	stem	leaves	root	stem	leaves	shoot
1	C	11.0	7.0	15.0	96	1054	1046	2100
	IR	11.1	6.9	15.9	129	1293	1213	2506
	B	8.9	7.7	15.7	82	1279	1049	2328
	R	9.6	6.8	15.2	116	1305	1173	2478
2	C	9.8	9.2	16.2	188	3302	1956	5258
	IR	10.0	9.2	16.1	216	3864	2129	5993
	B	10.1	10.4	16.8	279	4382	2340	6722
	R	10.2	11.4	17.2	260	4689	2328	7017
3	C	9.7	6.9	15.5	122	1481	1120	2601
	IR	9.5	6.8	15.3	120	1277	1109	2386
	B	9.8	6.3	15.4	98	1100	1081	2181
	R	9.3	6.6	16.1	136	1342	1174	2516
4	C	10.9	7.3	15.3	79	1036	936	1972
	IR	11.0	7.4	15.6	87	1294	1110	2404
	B	9.6	7.3	15.2	81	1152	891	2043
	R	9.9	7.6	16.5	90	1277	1109	2386
av. 1 - 4	C	10.4	7.6	15.5	121	1718	1265	2983
	IR	10.4	7.6	15.7	138	1932	1390	3322
	B	9.6	7.9	15.8	135	1978	1340	3319
	R	9.8	8.1	16.3	151	2153	1446	3599

* C = control,
IR = placed fertilizer between the rows,
B = broadcast fertilizer,
R = placed fertilizer next to the row

Table 13 Chlorophyll readings of the SPAD 502 in youngest fully expanded maize leave (in brackets the standard error of measurement of 20 plants)

experiment number	date	number of fully expanded leaves	treatment*	reading	s.e.
1	26-5-92	3-4	C	31.6	(2.7)
			IR	32.7	(3.0)
			B	33.4	(2.9)
			R	38.5	(3.3)
1	16-6-92	7	C	39.1	(1.8)
			IR	40.7	(2.3)
			B	40.6	(2.2)
			R	41.4	(2.8)
2	12-8-92	8	C	41.1	(1.7)
			IR	44.1	(1.7)
			B	43.8	(2.5)
			R	45.2	(1.8)
3	8-6-93	6-7	C	45.0	(1.9)
			IR	43.4	(1.6)
			B	41.8	(1.5)
			R	44.6	(2.3)
4	24-8-93	7	C	38.5	(2.0)
			IR	40.4	(2.0)
			B	39.7	(1.2)
			R	40.4	(1.6)

* C = control,
IR = placed fertilizer between the rows,
B = broadcast fertilizer,
R = placed fertilizer next to the row

Table 14. Leaf area index (LAI, $m^2\ m^{-2}$) and (on dry matter basis) shoot-root ratio (S/R), leaf-shoot ratio (L/S), leaf weight ratio (LWR, leafweight/(shoot+root weight)), specific leaf area (SLA, $cm^2\ g^{-1}$), relative growth rate (RGR, day^{-1}) and net assimilation rate (NAR, $g\ cm^{-2}\ day^{-1}$).

experiment number	treatment*	LAI	S/R	L/S	LWR	SLA	RGR	NAR
1	C	2.55	21.8	0.50	0.48	244	0.090	7.74
	IR	2.81	19.5	0.48	0.46	231	0.094	8.83
	B	2.63	28.3	0.46	0.44	251	0.092	8.42
	R	3.17	21.4	0.47	0.45	271	0.094	7.63
2	C	4.80	28.0	0.37	0.36	246	0.093	10.57
	IR	5.18	27.8	0.36	0.34	244	0.096	11.45
	B	5.29	24.1	0.35	0.33	226	0.098	12.97
	R	5.06	27.0	0.33	0.32	217	0.099	14.21
3	C	2.87	21.4	0.43	0.41	256	0.091	8.61
	IR	2.79	20.1	0.46	0.44	252	0.089	7.98
	B	2.88	22.4	0.50	0.47	266	0.087	6.90
	R	3.07	18.6	0.47	0.44	261	0.090	7.80
4	C	2.82	24.8	0.47	0.46	301	0.080	5.82
	IR	3.12	27.7	0.46	0.45	281	0.084	6.69
	B	2.91	25.4	0.44	0.42	327	0.081	5.88
	R	2.94	26.5	0.46	0.45	265	0.084	7.05
av. 1 - 4	C	3.26	24.0	0.44	0.43	262	0.089	8.19
	IR	3.48	23.8	0.44	0.42	252	0.091	8.74
	B	3.43	25.1	0.44	0.42	268	0.089	8.54
	R	3.56	23.4	0.43	0.42	254	0.091	9.17

* C = control,
IR = placed fertilizer between the rows,
B = broadcast fertilizer,
R = placed fertilizer next to the row

Table 15. Total N content of maize at harvest

experiment number	treatment*	total N (g 100 g^{-1}) roots	stem	leaves	shoot
1	C	1.18	1.61	2.48	2.04
	IR	1.32	2.44	2.91	2.67
	B	0.72	2.49	2.89	2.67
	R	1.87	2.42	2.91	2.65
2	C	1.03	1.95	3.21	2.42
	IR	1.16	2.47	3.20	2.73
	B	1.18	2.04	3.06	2.40
	R	1.56	2.02	3.16	2.40
3	C	1.68	3.21	3.89	3.50
	IR	1.77	3.54	3.97	3.74
	B	1.92	3.63	3.87	3.75
	R	1.95	3.56	3.82	3.69
4	C	1.38	2.95	3.58	3.25
	IR	1.37	2.83	3.61	3.19
	B	1.63	2.95	3.76	3.30
	R	1.71	2.87	3.70	3.26

* C = control,
IR = placed fertilizer between the rows,
B = broadcast fertilizer,
R = placed fertilizer next to the row

Table 16. Nitrate-N content of maize at harvest

experiment number	treatment*	NO_3-N (g 100 g^{-1})			
		roots	stem	leaves	shoot
1	C	0.07	0.29	0.07	0.18
	IR	0.20	0.81	0.20	0.51
	B	0.14	0.80	0.23	0.55
	R	0.38	0.83	0.23	0.55
2	C	0.10	0.83	0.19	0.59
	IR	0.15	1.16	0.30	0.86
	B	0.16	0.86	0.27	0.65
	R	0.20	0.81	0.23	0.62
3	C	0.16	1.16	0.34	0.81
	IR	0.18	1.38	0.40	0.92
	B	0.33	1.50	0.37	0.94
	R	0.47	1.41	0.35	0.91
4	C	0.21	0.85	0.37	0.62
	IR	0.27	0.88	0.33	0.63
	B	0.46	0.89	0.42	0.68
	R	0.52	0.90	0.30	0.62

* C = control,
IR = placed fertilizer between the rows,
B = broadcast fertilizer,
R = placed fertilizer next to the row

Table 17. N uptake of maize at harvest

experiment number	treatment*	N uptake (kg ha^{-1}) roots	stem	leaves	shoot
1	C	1	17	26	43
	IR	2	32	35	67
	B	1	32	30	62
	R	2	32	34	66
2	C	2	64	63	127
	IR	3	95	68	164
	B	3	90	72	161
	R	4	94	74	168
3	C	2	47	44	91
	IR	2	45	44	89
	B	2	40	42	82
	R	3	48	45	93
4	C	1	31	34	64
	IR	1	37	40	77
	B	1	34	34	67
	R	2	37	41	78

* C = control,
IR = placed fertilizer between the rows,
B = broadcast fertilizer,
R = placed fertilizer next to the row

Table 18. Fertilizer N recovery (%) in the shoot of maize based on the difference with control ('apparent recovery') and on istotope dilution, N derived from fertilizer (Ndf, kg ha^{-1}) and N derived from soil (Nds, kg ha^{-1}).

experiment number	treatment*	recovery based on		Ndf	Nds
		difference with control	isotopic dilution		
1	C	-	-	0	43
	IR	48	46	23	44
	B	38	36	18	44
	R	46	56	28	38
2	C	-	-	0	127
	IR	73	79	40	124
	B	68	59	30	132
	R	82	80	40	128
3	C	-	-	0	91
	IR	-4	13	7	83
	B	-19	29	14	67
	R	3	45	23	70
4	C	-	-	0	64
	IR	25	20	10	67
	B	7	21	11	57
	R	28	33	16	62

* C = control,
IR = placed fertilizer between the rows,
B = broadcast fertilizer,
R = placed fertilizer next to the row

Table 19A. Fertilizer N recovery (%) in the soil based on istotopic dilution at the start and end of Experiments 1 and 2.

treatment*		experiment and date											
	po sition**	1 (4-5-1992)			1 (22-6-1992)			2 (20-7-1992)			2 (31-8-1992)		
	layer (cm)	r	ir	m	r	ir	m	r	ir	m	r	ir	m
IR	0 - 10	6	5	5	1	1	1	0	133	67	0	0	0
	10 - 20	3	1	2	0	0	0	0	7	3	0	0	0
	20 - 30	0	1	0	0	1	0	0	0	0	0	0	0
	30 - 50	0	0	0	0	0	0	0	1	1	0	-1	0
	50 - 70	0	0	0	0	0	0	1	0	0	0	0	0
	70 - 170			1			-1			0			0
	0 - 170			8			0			75			0
B	0 - 10	17	25	21	4	27	15	79	53	66	0	0	0
	10 - 20	2	2	2	0	4	2	7	2	4	0	0	0
	20 - 30	0	0	0	0	0	0	1	0	1	0	0	0
	30 - 50	0	0	0	1	0	0	0	1	1	0	2	1
	50 - 70	0	0	0	1	0	0	0	0	0	0	0	0
	70 - 170			0			-2			0			0
	0 - 170			23			16			72			1
R	0 - 10	151	0	75	1	2	1	217	1	109	0	0	0
	10 - 20	0	0	0	0	0	0	1	0	1	0	0	0
	20 - 30	0	0	0	0	0	0	0	42	21	0	0	0
	30 - 50	0	0	0	0	0	0	0	0	0	0	0	0
	50 - 70	0	0	0	0	-	0	0	0	0			0
	70 - 170			0			-2			0			0
	0 - 170			75			-1			132			0

* C=control, IR=placed fertilizer between t0he rows, B=broadcast fertilizer, R=placed fertilizer next to the row

* C = control,
IR = placed fertilizer between the rows,
B = broadcast fertilizer,
R = placed fertilizer next to the row

** r=under the maize row, ir=between the maize row, m=mean of both values (0-70 cm) or random sample (70-170 cm)

Soon after application, N was only partly recovered in the soil. The increase in SMN supply was generally much less than the theoretical 50 kg per ha (Appendix 5) and recoveries in the soil solution were generally substanstially less than 100 % (in all but Experiment 2), probably due losses and the onset of crop uptake (Table 19). At the end of Experiments 1 and 2 hardly any fertilizer N was recovered in the soil solution according to the isotope dilution method. In Experiments 3 and 4, however, on average 39 and 52 % of the fertilizer remained in the soil after harvest (Table 19). The sum of N recoveries in the crop (Table 18) and the upper 0-70 cm soil layer (Table 19A and 19B), amounted to on average 52, 73, 68 and 77 % for Experiments 1, 2, 3 and 4, respectively. Especially in Experiments 3 and 4, SMN supplies at the time of harvest were somewhat higher in fertilized treatments (Figure 5; Table 20)

Apparent N mineralization in the upper 70 cm between the start and end of the control treatments of Experiments 1, 2, 3 and 4 amounted to 32, -13, 5 and 9 kg per ha, respectively (Table 20). Apparent mineralization of fertilized treatments, was substantially lower in Experiment 1, indicating that a part of the fertilizer-N was either temporarily or permanently lost. In Experiments 2 and 3 apparent mineralization was smaller again in fertilized treatments than in the corresponding control treatments. In those two experiments, however, differences were smaller if the balance sheet calculations included deeper layers. This indicates that some fertilizer-N may have been leached. In Experiment 4 apparent mineralization of fertilized treatments exceeded the control suggesting a priming effect. Again, this may have coincided with downward transport of N as the priming effect increased as calculations included deeper layers.

Table 19B. Fertilizer N recovery (%) in the soil based on istotopic dilution at the start and end of Experiments 3 and 4

treatment*	po sition**	1 (4-5-1993)			1 (14-6-1993)			2 (19-7-1993)			2 (30-8-1993)		
	layer (cm)	r	ir	m	r	ir	m	r	ir	m	r	ir	m
IR	0 - 10	1	91	46	1	36	19	12	8	10	3	7	5
	10 - 20	-	0	0	2	27	14	0	1	1	0	72	36
	20 - 30	0	0	0	0	7	4	1	0	0	11	17	14
	30 - 50	1	1	1	7	6	6	-1	0	-1	6	0	3
	50 - 70	0	0	0	7	0	4	0	0	0	0	0	0
	0 - 70			47			47			10			58
B	0 - 10	33	17	25	3	20	11	-	-	-	5	17	11
	10 - 20	-	7	7	3	10	6	17	14	16	15	3	9
	20 - 30	1	1	1	0	0	0	4	1	2	12	19	16
	30 - 50	4	3	3	3	3	3	3	2	3	11	0	5
	50 - 70	2	4	3	8	7	7	2	2	2	-1	-1	-1
	0 - 70			39			27			-			40
R	0 - 10	92	1	47	13	2	7	114	-	114	7	1	4
	10 - 20	0	0	0	8	1	5	-	-	-	70	5	37
	20 - 30	0	1	0	3	4	3	-	-	-	31	5	18
	30 - 50	1	1	1	8	31	19	-	-	-	0	0	0
	50 - 70	17	25	21	0	18	9	-	-	-	0	0	0
	0 - 70			69			43		-				59

* C=control,
IR=placed fertilizer between the rows,
B=broadcast fertilizer,
R=placed fertilizer next to the row

** r=under the maize row,
ir=between the maize row,
m=mean of both values (0-70 cm)
or random sample (70-170 cm)

Table 20A. Balance sheet calculations for estimation of the net N mineralization (kg ha^{-1})

experiment	treatment**	layer (cm)	SMNE+	NYLD-	SMNS-	NFER=	ANMI	CANMI*
1	C	0 - 20	0	43	10	0	33	
		0 - 50	9	43	23	0	29	
		0 - 70	21	43	32	0	32	
	IR	0 - 20	1	67	10	50	8	-25
		0 - 50	8	67	23	50	2	-27
		0 - 70	22	67	32	50	7	-25
	B	0 - 20	17	62	10	50	19	-14
		0 - 50	26	62	23	50	15	-14
		0 - 70	39	62	32	50	19	-13
	R	0 - 20	4	66	10	50	10	-23
		0 - 50	14	66	23	50	7	-22
		0 - 70	28	66	32	50	12	-20
2	C	0 - 20	0	127	40	0	87	
		0 - 50	1	127	98	0	30	
		0 - 70	2	127	142	0	-13	
	IR	0 - 20	0	164	40	50	74	-13
		0 - 50	5	164	98	50	21	-9
		0 - 70	22	164	142	50	-6	7
	B	0 - 20	0	161	40	50	71	-16
		0 - 50	2	161	98	50	15	-15
		0 - 70	14	161	142	50	-17	-4
	R	0 - 20	0	168	40	50	78	-9
		0 - 50	1	168	98	50	21	-9
		0 - 70	17	168	142	50	-7	6

* SMNE and SMNS = soil mineral N at the end and start of an experiment,
NYLD = N taken up by the shoot,
NFER = N-fertilizer applied,
ANMI = apparent N-mineralization,
CANMI = idem, corrected for apparent mineralization of control

** C=control,
IR=placed fertilizer between the rows,
B=broadcast fertilizer,
R=placed fertilizer next to the row

Table 20B. Balance sheet calculations for estimation of the net N mineralization (kg ha^{-1})

experiment	treatment**	layer (cm)	SMNE+	NYLD-	SMNS-	NFER=	ANMI	CANMI*
3	C	0 - 20	4	91	43	0	52	
		0 - 50	26	91	105	0	12	
		0 - 70	52	91	138	0	5	
	IR	0 - 20	32	89	43	50	28	-24
		0 - 50	67	89	105	50	1	-11
		0 - 70	100	89	138	50	1	-4
	B	0 - 20	29	82	43	50	18	-34
		0 - 50	57	82	105	50	-16	-28
		0 - 70	94	82	138	50	-12	-17
	R	0 - 20	29	93	43	50	29	-23
		0 - 50	64	93	105	50	2	-10
		0 - 70	97	93	138	50	2	-3
4	C	0 - 20	4	64	60	0	8	
		0 - 50	60	64	135	0	-11	
		0 - 70	129	64	184	0	9	
	IR	0 - 20	50	77	60	50	17	9
		0 - 50	131	77	135	50	23	34
		0 - 70	181	77	184	50	24	15
	B	0 - 20	25	67	60	50	-18	-26
		0 - 50	118	67	135	50	0	11
		0 - 70	179	67	184	50	12	3
	R	0 - 20	41	78	60	50	9	1
		0 - 50	140	78	135	50	33	44
		0 - 70	189	78	184	50	33	24

* SMNE and SMNS = soil mineral N at the end and start of an experiment,
NYLD = N taken up by the shoot, NFER = N-fertilizer applied, ANMI = apparent N-mineralization,
CANMI = idem, corrected for apparent mineralization of control

** C=control,
IR=placed fertilizer between the rows,
B=broadcast fertilizer, R=placed fertilizer next to the row

Table 21. N-uptake in the shoot, calculated absolute contribution from mass flow and diffusion plus interception (kg N per ha) and the relative proportion of diffusion plus interception in the N accumulation (%).

Treatment *	experiment 1		2		3		4	
	C	B	C	B	C	B	C	B
N uptake	43	62	127	161	91	82	64	67
N from mass flow (abs.)	12	27	39	71	51	52	64	67
N from diffusion and interception (abs.)	31	35	88	90	40	30	0	0
N from diffusion and interception (rel.)	72%	56%	69%	56%	44%	37%	0%	0%

* C=control, B=broadcast fertilizer

Assuming that evaporation accounted for half of the evapotranspiration (with a maximum of 0.5 mm per day), soil water content was on average 170 g per kg and soil bulk density amounted to 1.4 kg per liter, data of evapotranspiration (Table 7), rooting depth (Appendix 4) and soil mineral N (Appendix 5) can be used for a rough approximation of the N transport via massflow on the one hand and uptake via diffusion and interception on the other hand (Table 21). According to these calculations, diffusion and interception contributed for 40-70 percent to the shoot N uptake in Experiments 1, 2 and 3. Obviously, diffusion and interception became more important at low N concentrations in the soil (i.e. control plots). Calculations indicated that N demand could be covered completely by mass flow in Experiment 4, due to the high N supply in both fertilized and unfertilized treatments.

4. Discussion

Nutrient recovery can be improved by a better synchronisation and synlocalisation of (solutions of) nutrients and (active) roots (De Willigen & Van Noordwijk, 1987). In 1992 and 1993 we carried out four experiments in the Wageningen Rhizolab to find out whether the recovery of N by a maize crop can be explained in terms of the spatial and temporal distribution of the root system.

Synchronisation and synlocalisation will be qualified as inadequate if the exploitable nutrient supply is low relative to the demand. As a overal low soil temperature restricts N availability via its effects on the specific root length, root growth rate, root functioning and rooting depth (Tardieu & Pellerin, 1991; Engels & Marschner, 1990) and mineralization, two of the experiments were planted in early spring in order to evoke some cold stress. We did not obtain this stress, however, because temperature was substantially higher than normal and initial SMN supplies were high due to mineralization over winter.

On average, root length density as measured in core samples circa 53 days after emergence, varied from 4.8 cm per cm^3 right under the plant row to 1.6 cm per cm^3 between the rows and 0.6 cm per cm^3 at a depth of 60 cm. Values are in close agreement with those obtained in maize crops of similar age by De Willigen & Van Noordwijk (1987) and Barber & Kovar (1991). The ratio between these root length density values and the observed number of intersections on minirhizotron walls on corresponding positions and date (Lrv/n) amounted to 1.13, 1.76, 0.99 and 1.21 for Experiments 1, 2, 3 and 4, respectively. This is much less than 2, what would be expected for randomly growing roots (Melhuish & Lang, 1968; Lang & Melhuish, 1970). This may indicate preponderance of vertically growing roots. Chaudhary & Prihar (1974) as well as Tardieu & Pellerin (1991) found that low temperatures caused maize root to grow less steeply downward which would cause a negative relationship between temperature and Lrv/n values. In our experiments, however, a positive relationship could be observed between the value of Lrv/n and the average daily soil temperature between planting and harvest. Maybe other factors such as loss of fine roots during the processing of core samples, have also resulted in relatively low Lrv/n values.

Close relationships (VAF 41-87 %) were found between thermal time and root length density. According to these relationships the first maize roots penetrated to a depth of 60 cm within 81-101 days at a temperature of 13 °C and 50-63 days at a temperature of 16 °C, suggesting growth rates of 0.6-1.2 cm per day. Such rates are in good agreement with the results of Foth (1962) and De Willigen & Van Noordwijk (1987). At temperatures of 13 °C and 16 °C, respectively, it would cost another 16-85 and 10-54 days to achieve a root length density of at least 0.5 cm per cm^3 on any lateral position at a depth of 60 cm. Likewise, it can be calculated that the first roots arrive at a lateral distance of 26-30 cm within 17-38 days at a temperature of 13 °C and 11-24 days at temperature of 16 °C. The lateral extension rate was highest where SMN supply in the proximity of the plant row was low (control and treatment with N placement between the rows). N placement between the rows may have promoted lateral root extension (Granato & Raper, 1989). Days needed to arrive at a distance of 26-30 cm are in good agreement with the range of 14-50 days that can be derived from the combined data of Foth (1962), Chaudhary & Prihar (1974), Mengel & Barber (1974) and De Willigen & Van Noordwijk (1987). This would imply lateral growth rates of 0.7-2.5 cm per day. The 15-20 cm layer was the first one to be exploited by roots between the rows. Yet it lasted another 18-27 and 10-18 days at temperatures of 13 and 16 °C, respectively, before root length density in the 15-20 cm layer was at least 0.5 cm per cm^3. For shallower layers, however, at least 72 and 45 days were needed to achieve similar root length densities at temperatures of 13 and 16° C, respectively. This may have implications for the availability of post emergence N dressings under dry conditions if N is applied as a band dressing between the rows.

SMN was not evenly distributed through the profile. Vertical gradients resulting from fertilizer application, fainted gradually in time due to crop uptake losses. Horizontal gradients resulting from N placement weakened in time. For the control and broadcast N applications, however, a gradient was built up as time passed by. In agreement with the findings of Aufhammer (1991) these crops left more SMN between the rows than right under the row.

N-application had a positive effect on the NO_3-N content of the shoot, LAI, chlorophyll content, and on N uptake and DM yield except for Experiment 3 where especially the fertilized treatments suffered from herbicide drift (see Paragraph 2.4.2). Response was generally strongest in Experiments 1 and 2 where SMN supplies were relatively low. In agreement with Wood et al. (1992) and Piekielek & Fox (1992) we found a positive relationship between SPAD readings (chlorophyll), leaf N content and yield.

There were no indications that LAI, chlorophyll content, NO_3-N content or shoot DM yield benefitted more from N placed next to the row than from N placed between the rows. Compared with both these placement methods, broadcast application of N resulted in a smaller N uptake and shoot DM yield in all four experiments. Only in Experiment 2, broadcast N was superior to N placed between the rows.

N recoveries in the crop increased in the order broadcast N, placed N between the rows and placed N next to the row. Recoveries based on isotopic dilution are usually smaller than recoveries based on the difference method (Varvel & Peterson, 1990; Timmons & Baker, 1991; Blaylock & Cruse, 1992; Torbert et al., 1992) due to so called added N interactions (Rao et al., 1992). In our experiments both methods gave similar results, however. This may imply that the occurrence of isotope substitution was limited (which would have decreased recovery based on isotopic dilution) even for broadcast N (Maddux et al., 1991). However, the results of experiment 4 showing both a priming effect and a crop plus soil ^{15}N recovery of only 77 %, suggested substitution of ^{14}N in organic matter by ^{15}N from fertilizer. So, as the absence of isotope substitution can not fully explain the fair agreement between recoveries based on ^{15}N and those based on the difference method, the agreement of both methods may also have been caused by an incomplete exploitation of the soil in fertilized crops (which would decrease recovery based on the difference method). Indeed, both core samples (except for Experiment 4) and minirhizotron observations (except for the R-treatment) indicated that the extremes of the profile were better exploited in terms of root length density in the control than in fertilized treatments. This coincided with smaller amounts of residual SMN as assessed in ceramic cup and RHIZON SSS sampling, in the extreme soil compartments of the control than in corresponding compartments of fertilized treaments.

In the Experiments 1, 2 and 3, the apparent mineralization in the upper 50 cm soil layer was lower for fertilized treatments than for the control, suggesting losses of fertilizer N during the first 7 weeks after emergence. For the broadcast N treatment, these calculated losses amounted to 28 % of the applied fertilizer in Experiment 1. As losses were similar if the 50-70 cm soil layer was included and no N leaching into the 70-170 cm layer seems to have taken place

(Appendix 5), losses are probably due to denitrification and/or immobilisation in that experiment. In Experiment 2, losses of broadcast fertilizer N were limited to 8 % if the 50-70 cm soil layer was included in the balance sheet calculations. N enrichment of the 70-170 cm soil layer (Appendix 5) indicated that leaching accounted for the losses in that experiment. In Experiment 3, losses of broadcast fertilizer N amounted to 34 % even the 50-70 cm layer was included. As N enrichment of deeper layers could not be observed (Appendix 5), losses appear to have been caused by denitrification and/or immobilisation, again.

Acknowledgement

The technical assistance of Mr G. Versteeg is greatly appreciated.

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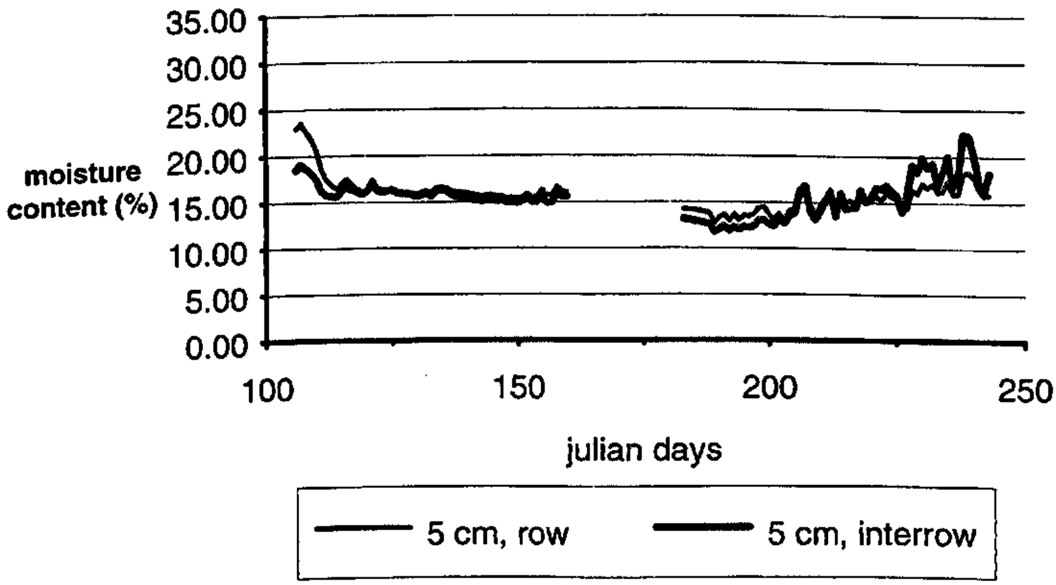
Appendix I:
Treatment allocation

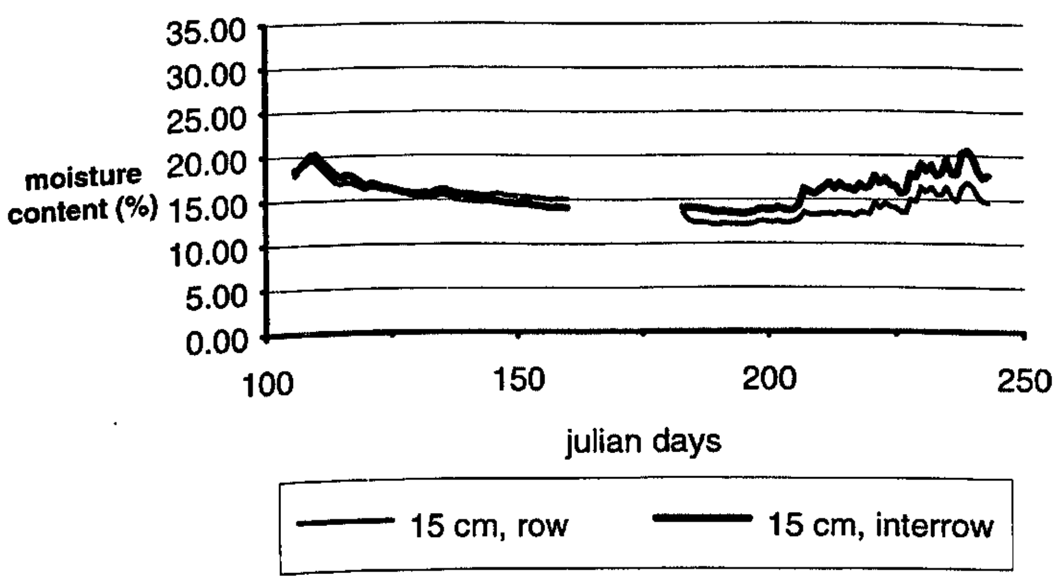
Appendix 1. Allocation of treatments to Wageningen Rhizolab compartments 10, 12, 14 and 16

treatment*	experiment			
	1	2	3	4
C	14	10	10	16
IR	10	12	12	14
B	16	14	16	12
R	12	16	14	10

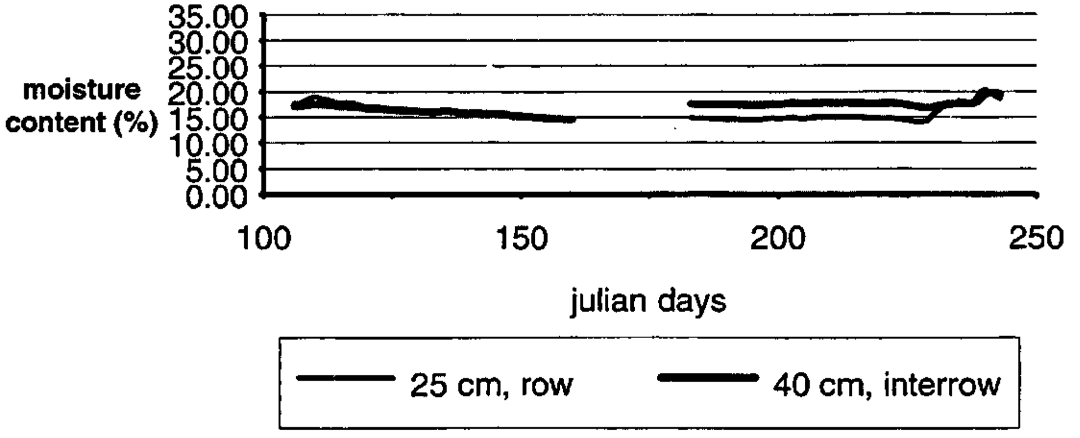
* C=control,
IR=placed fertilizer in between the rows,
B=broadcast fertilizer,
R=placed fertilizer next to the row

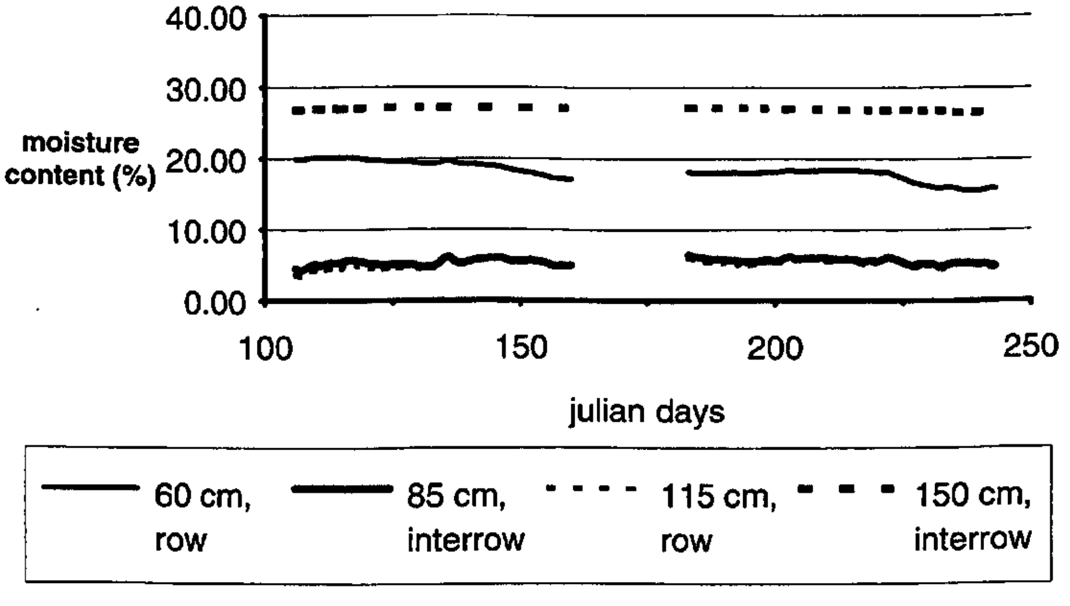
Appendix II:
Moisture content



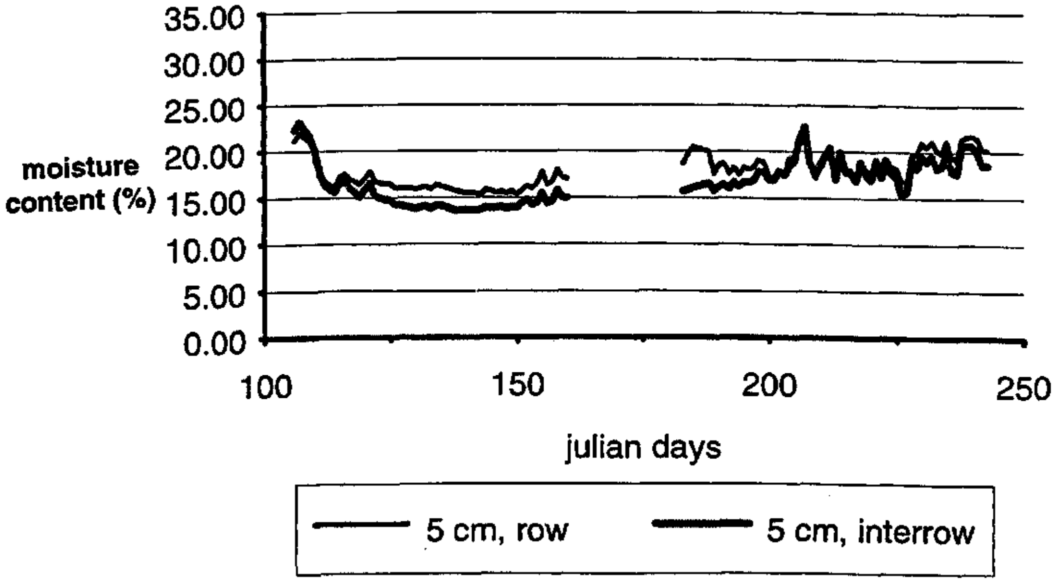


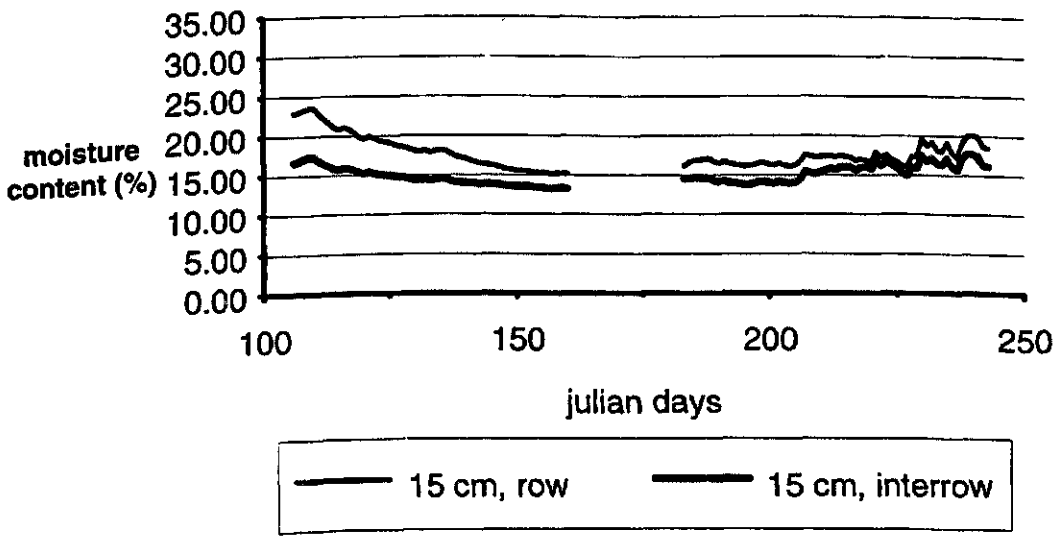
Appendix 2.1 Moisture content; Experiments 1 and 2; compartment: 10



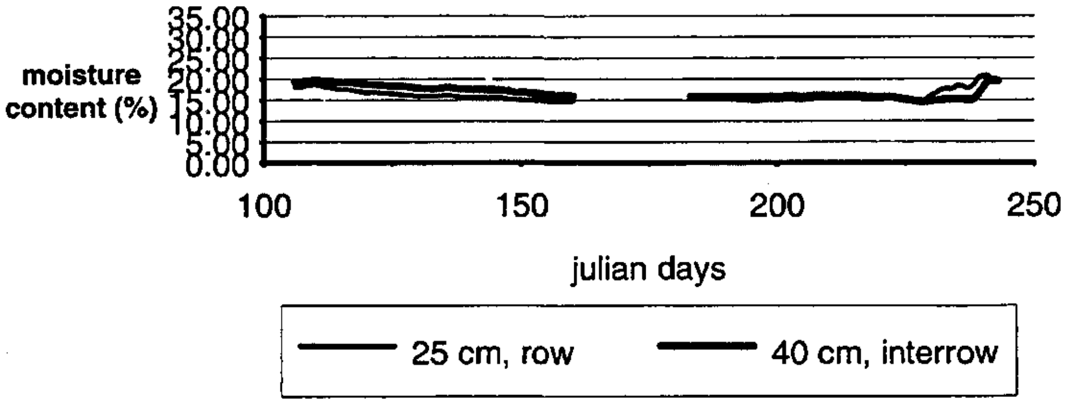


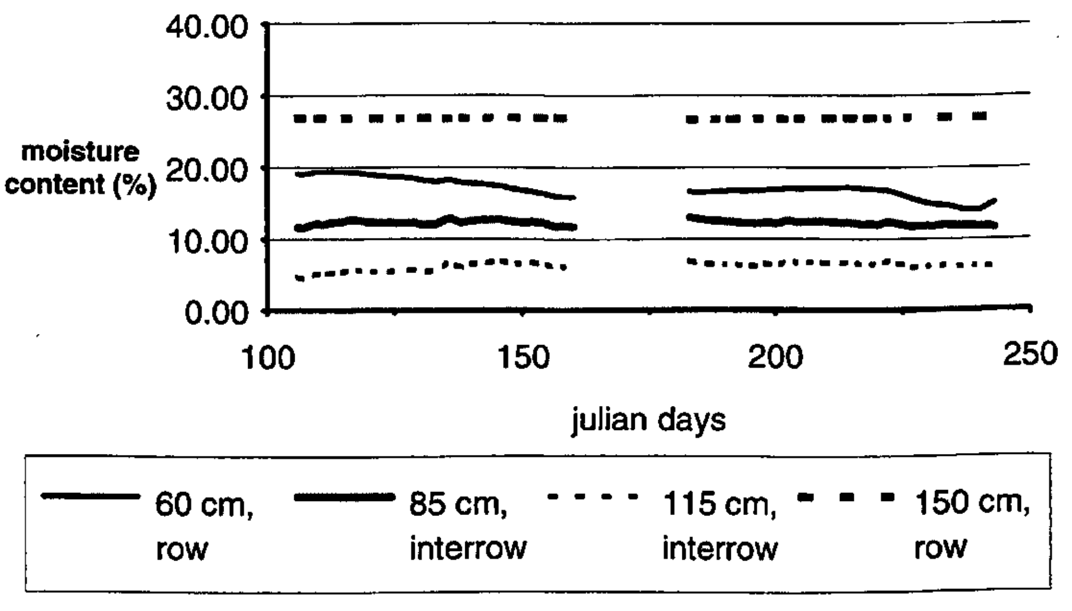
Appendix 2.1 Moisture content; Experiments 1 and 2; compartment: 10



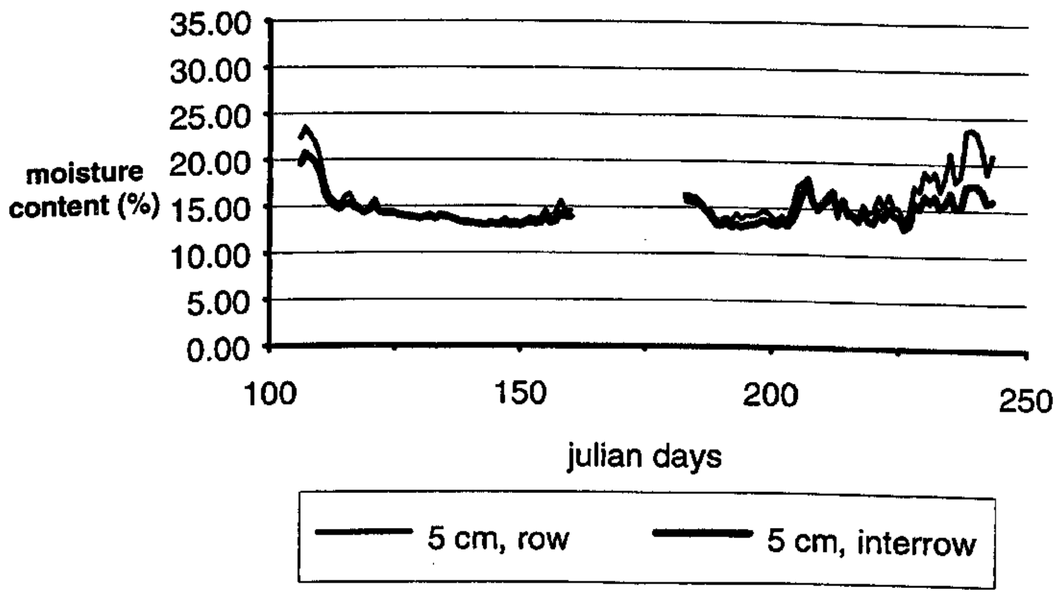


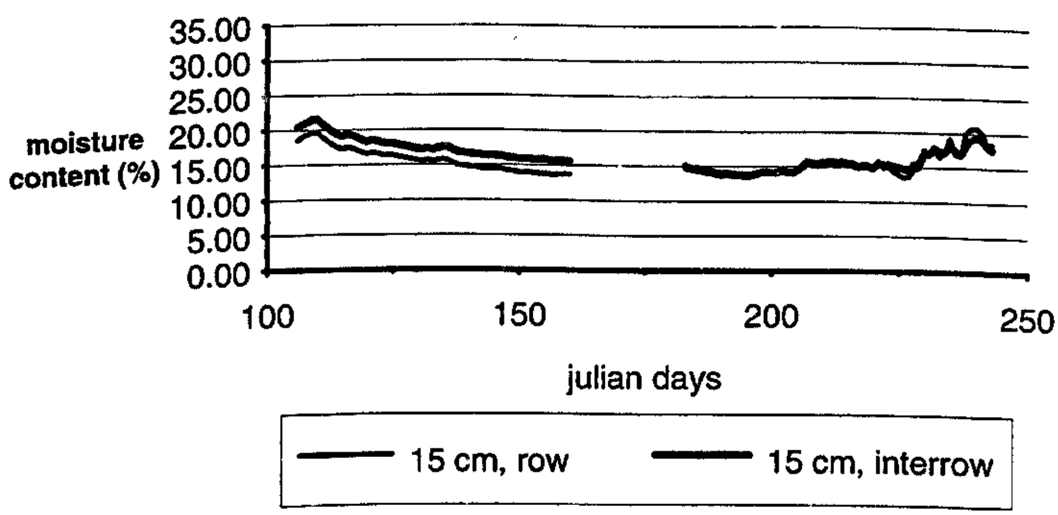
Appendix 2.2 Moisture content; Experiments 1 and 2; compartment: 12



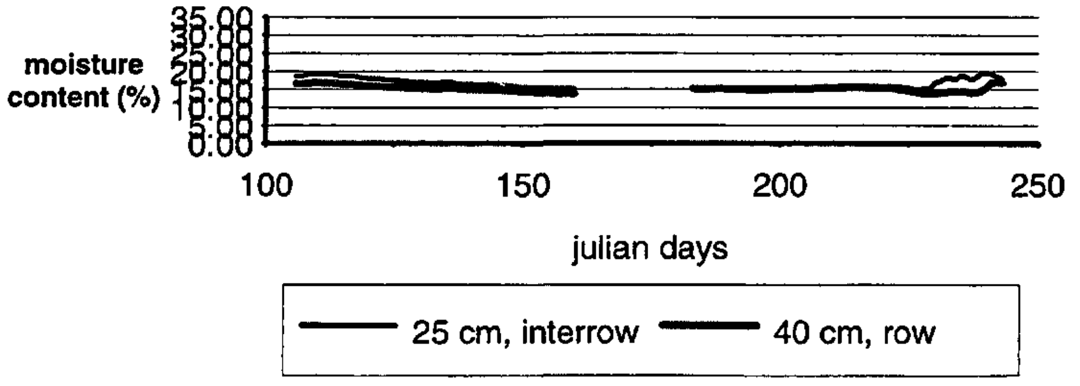


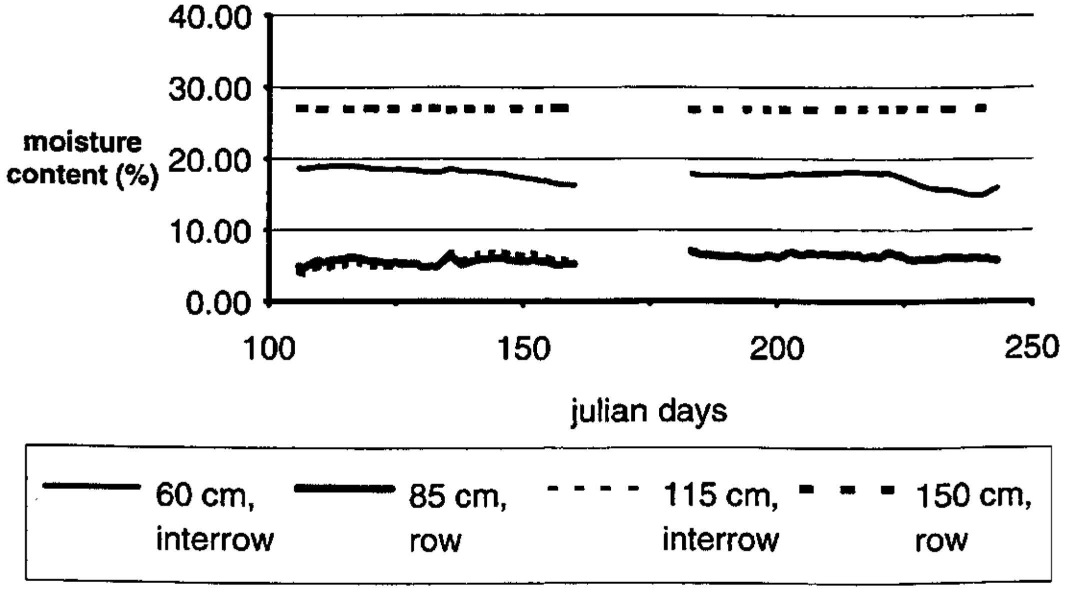
Appendix 2.2 Moisture content; Experiments 1 and 2; compartment: 12



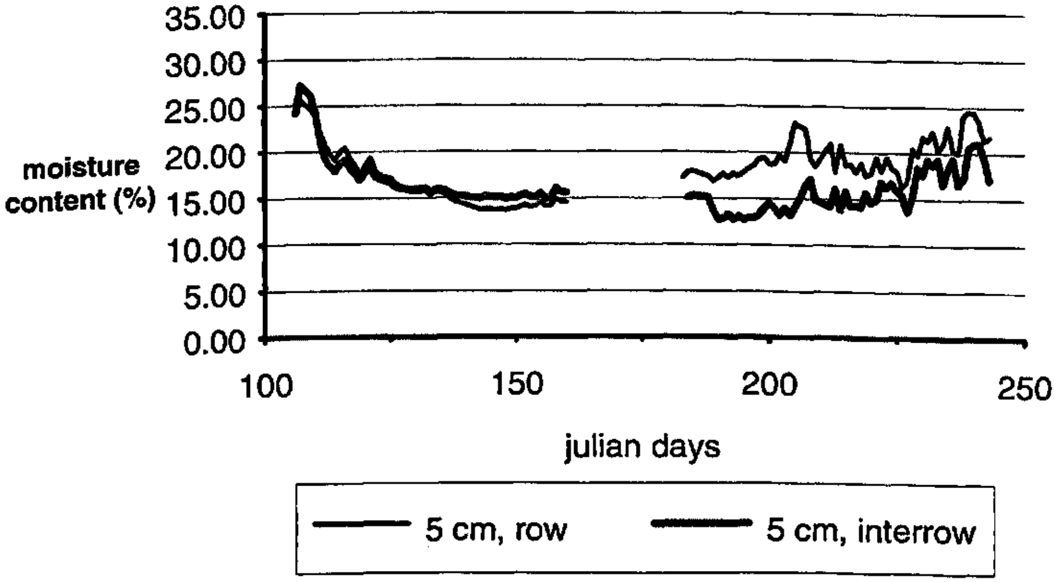


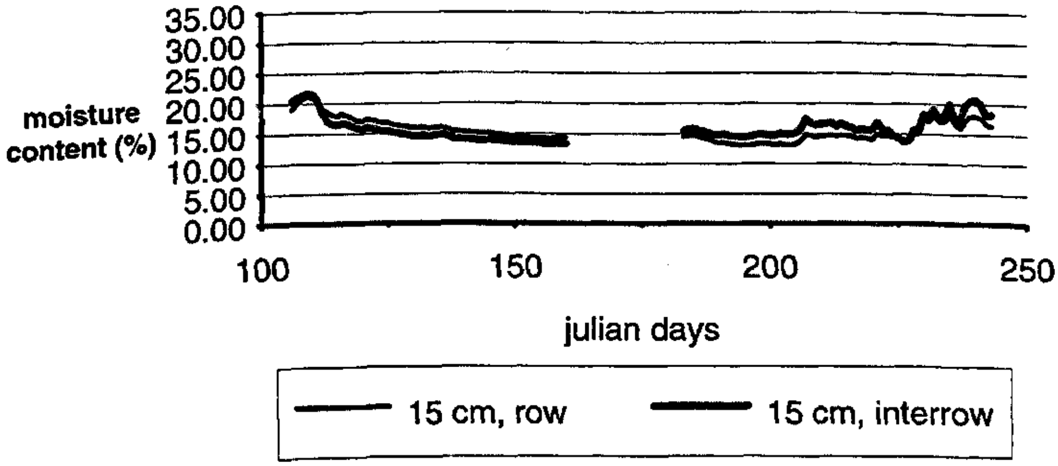
Appendix 2.3 Moisture content; Experiments 1 and 2; compartment: 14



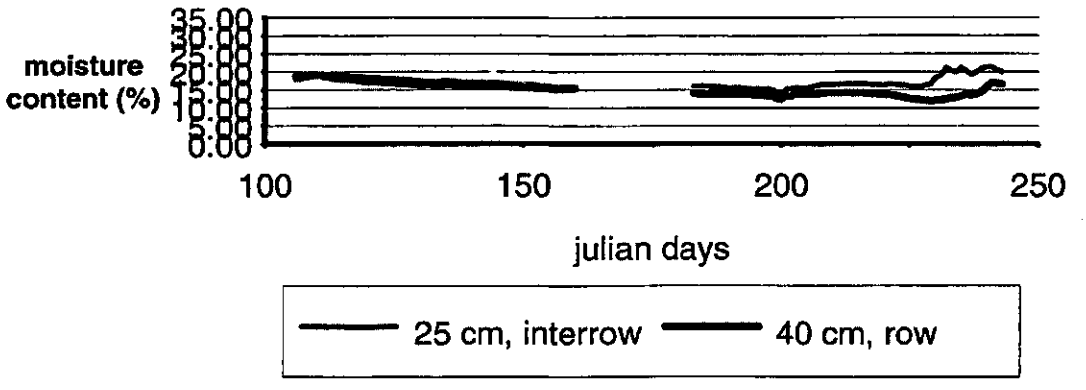


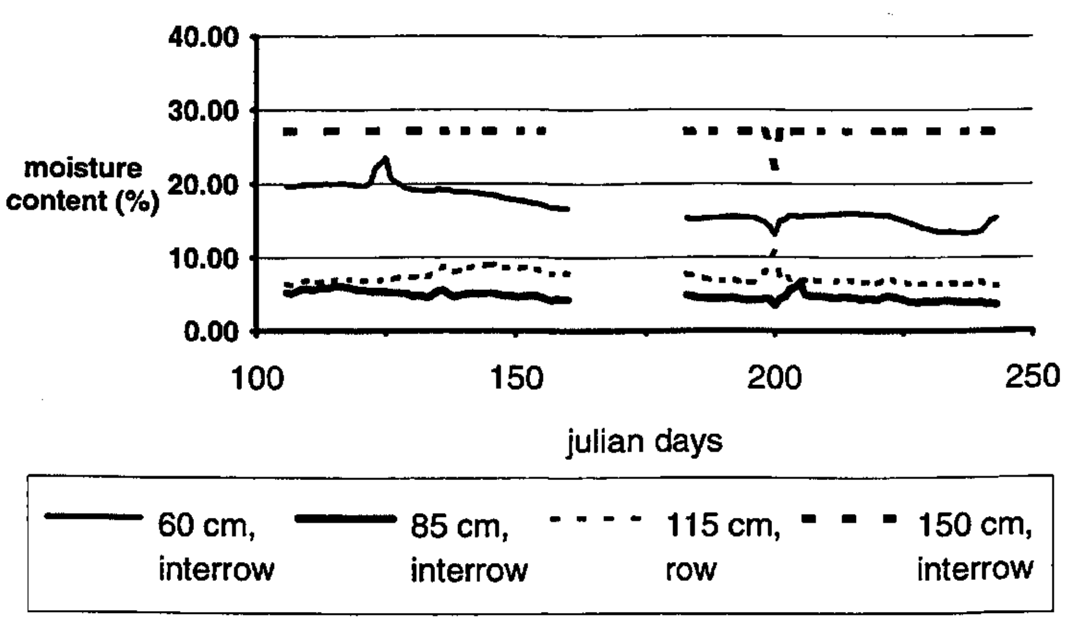
Appendix 2.3 Moisture content; Experiments 1 and 2; compartment: 14



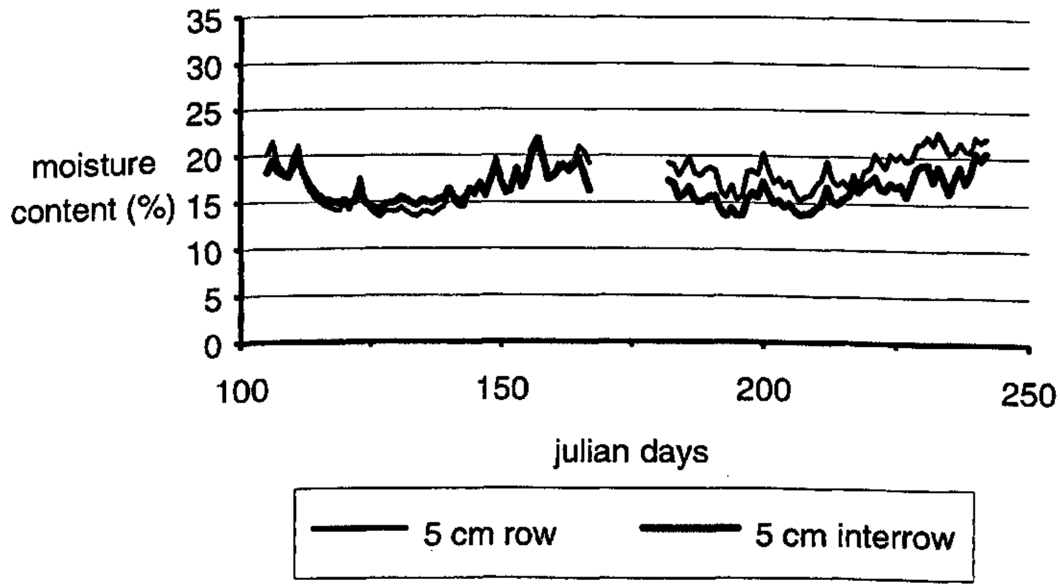


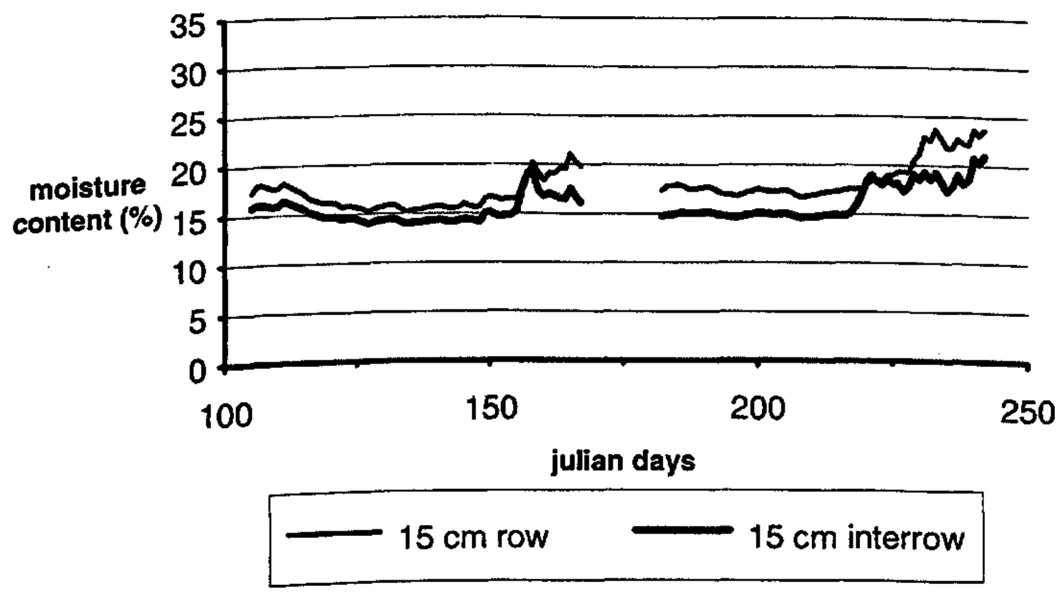
Appendix 2.4 Moisture content; Experiments 1 and 2; compartment: 16



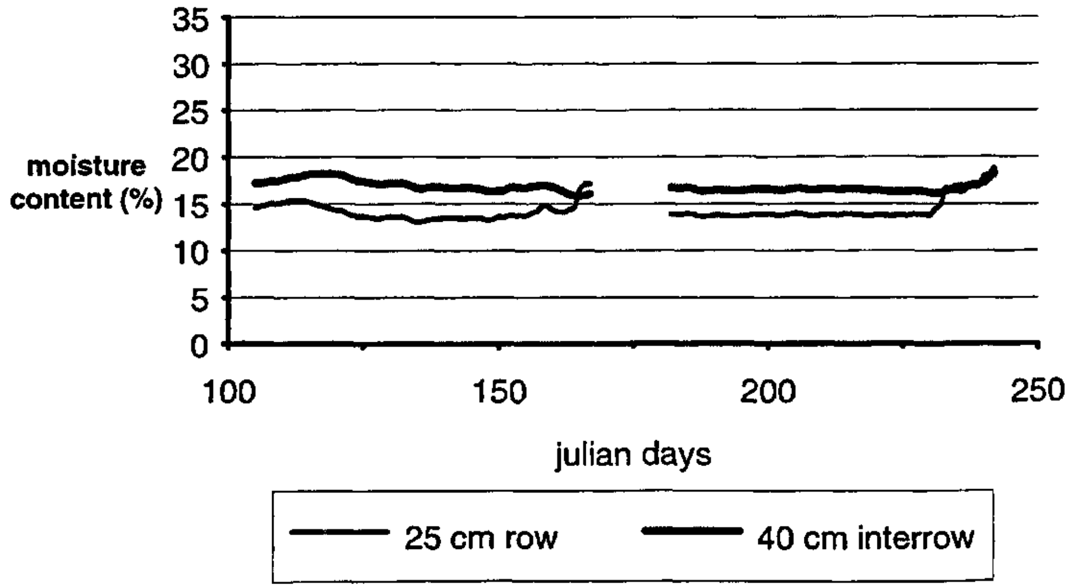


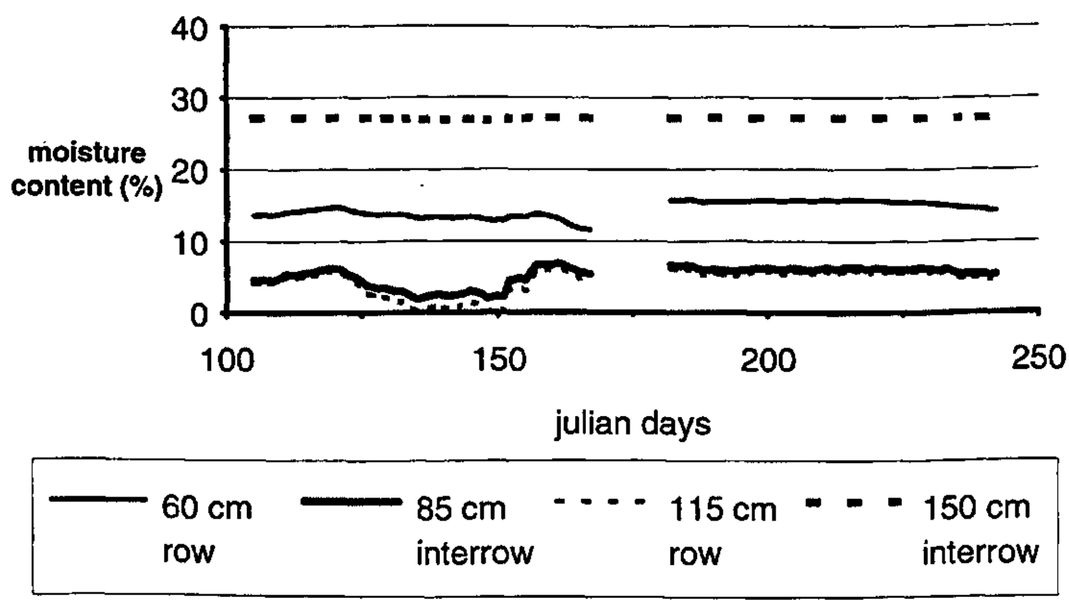
Appendix 2.4 Moisture content; Experiments 1 and 2; compartment: 16



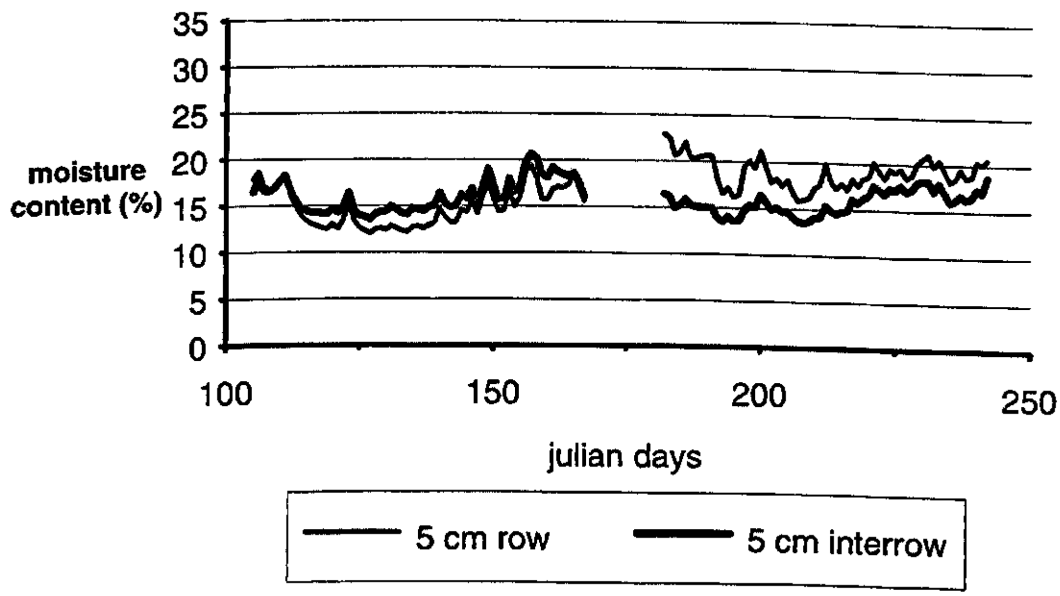


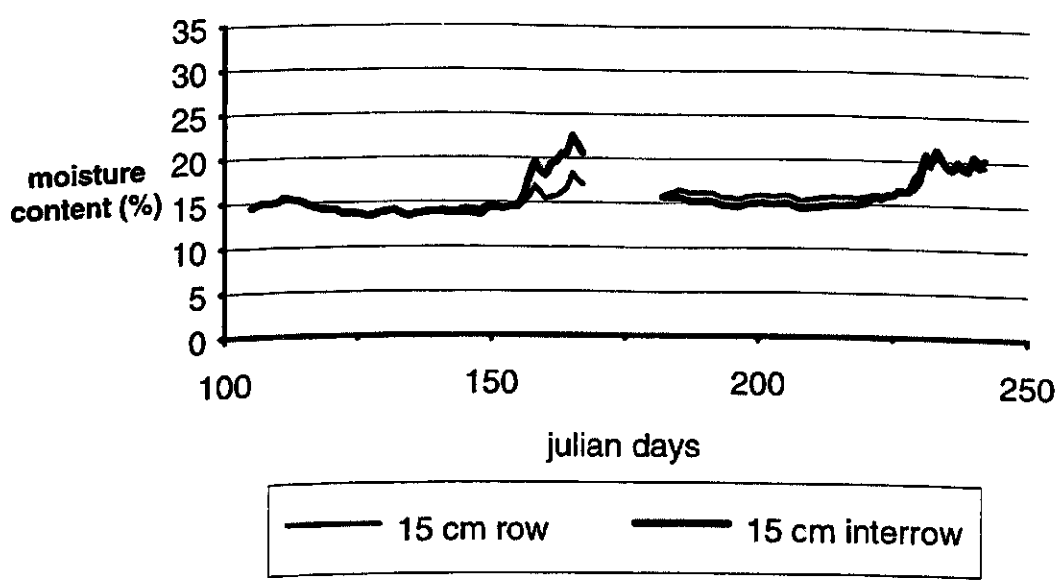
Appendix 2.5 Moisture content; Experiments 3 and 4; compartment: 10



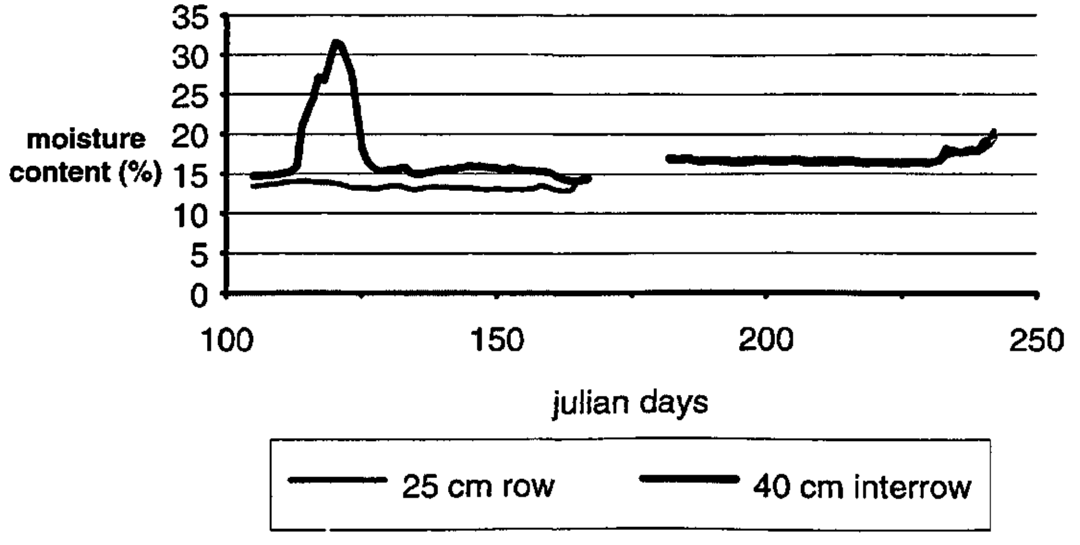


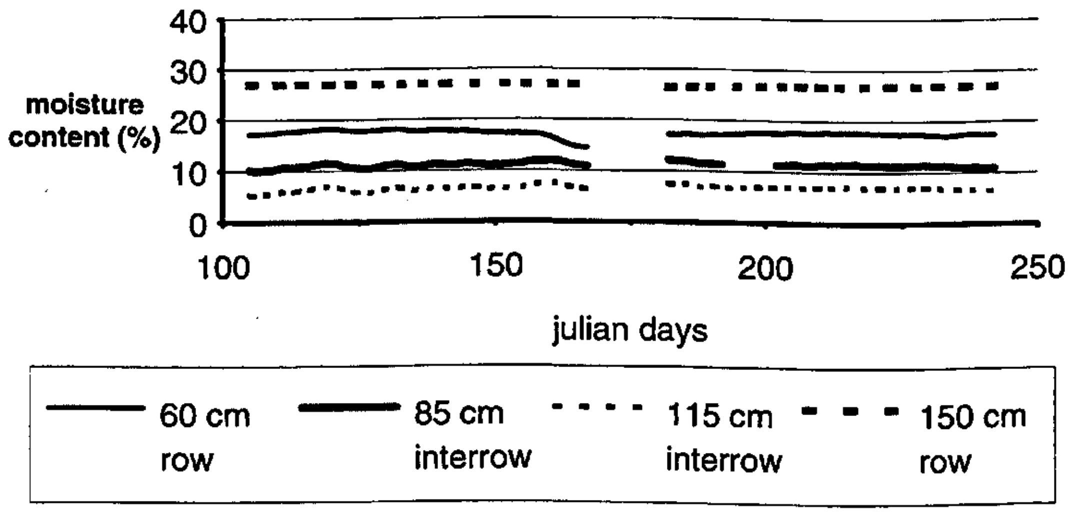
Appendix 2.5 Moisture content; Experiments 3 and 4; compartment: 10



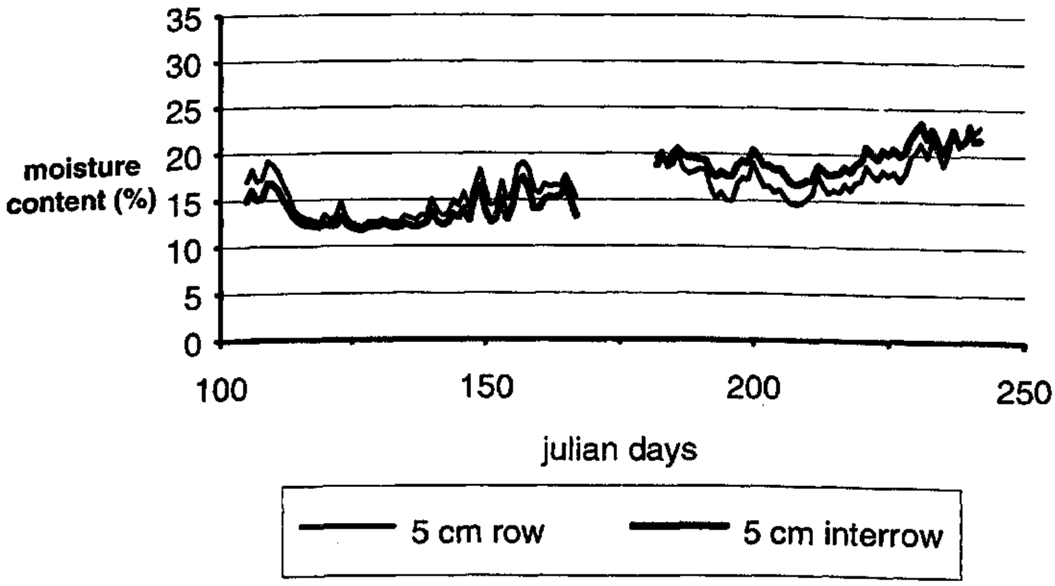


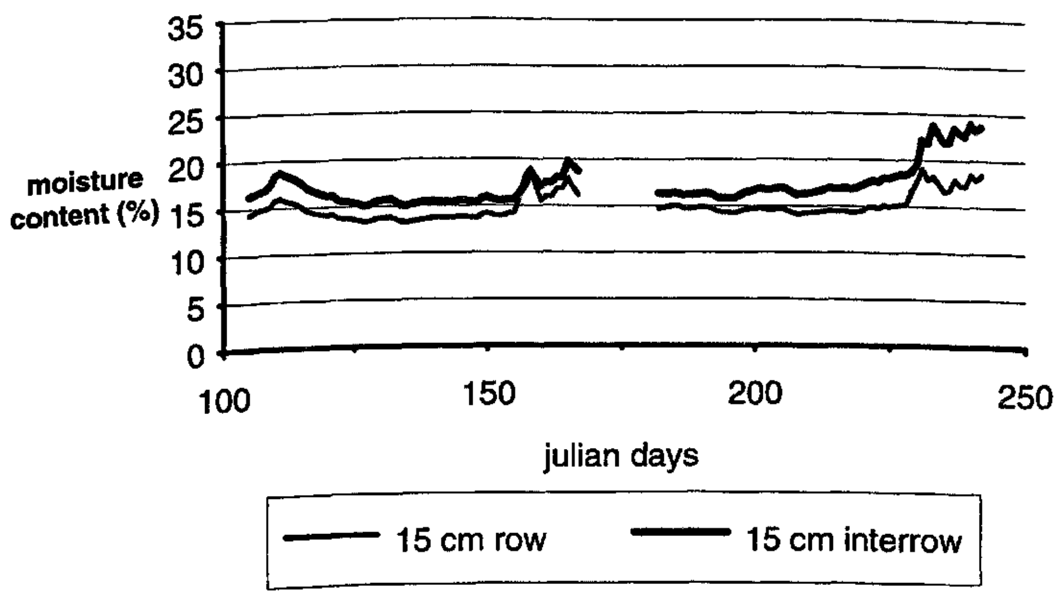
Appendix 2.6 Moisture content; Experiments 3 and 4; compartment 12



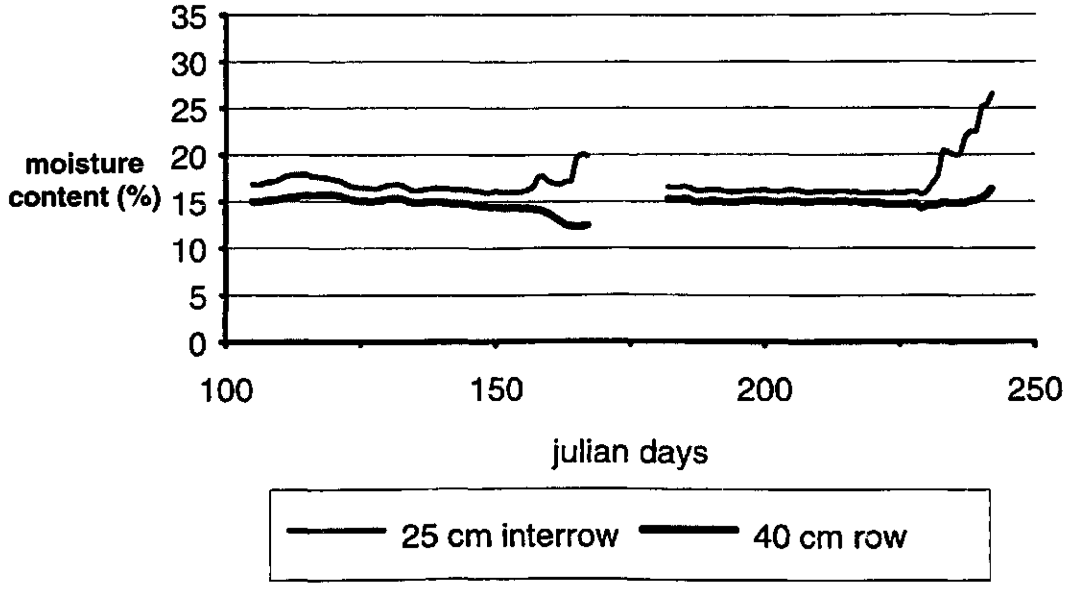


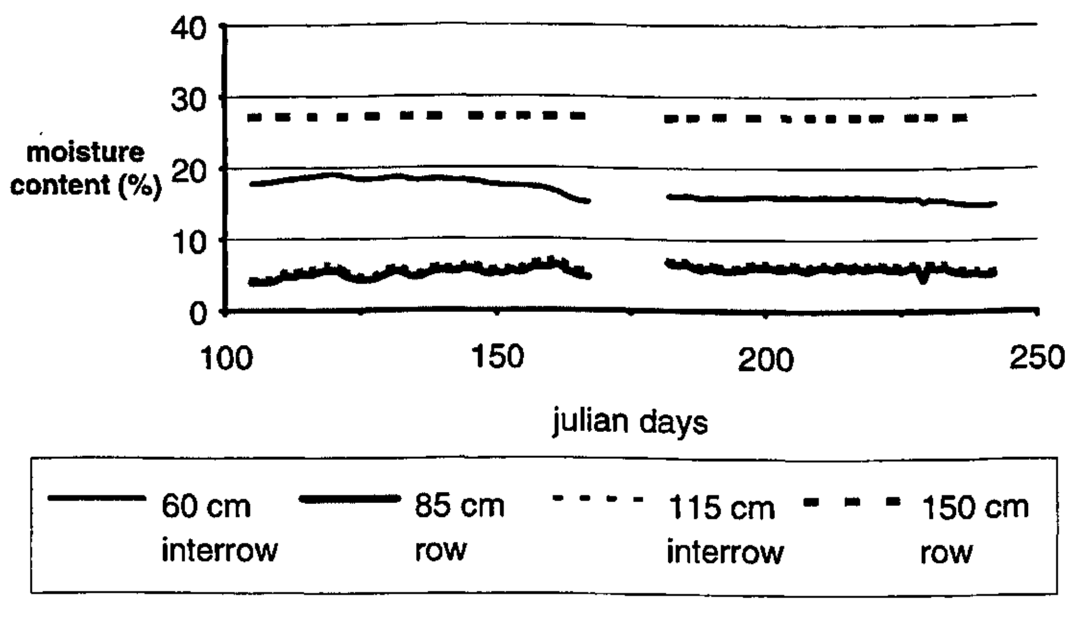
Appendix 2.6 Moisture content; Experiments 3 and 4; compartment 12



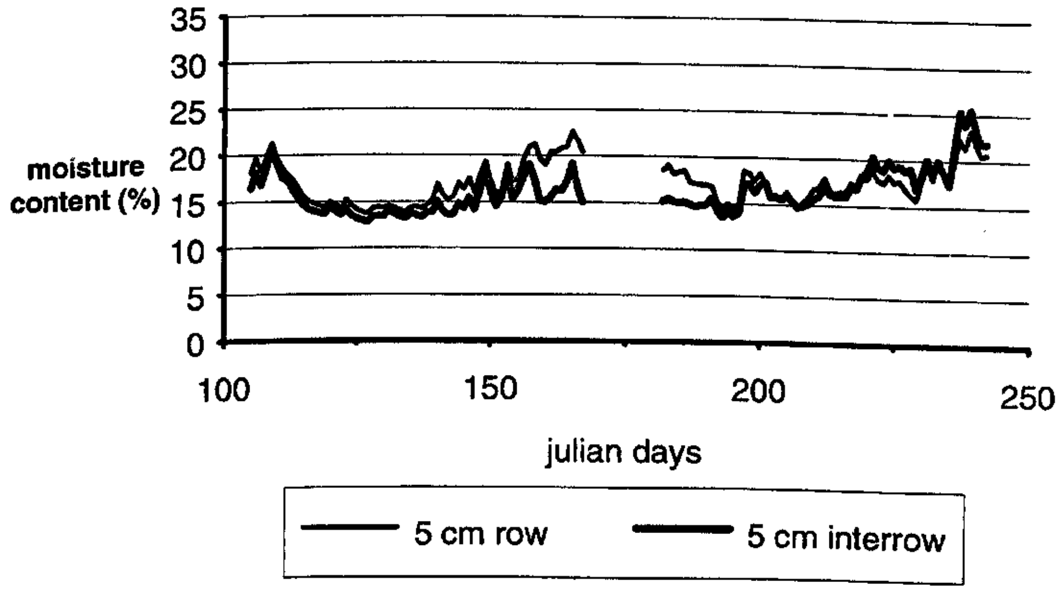


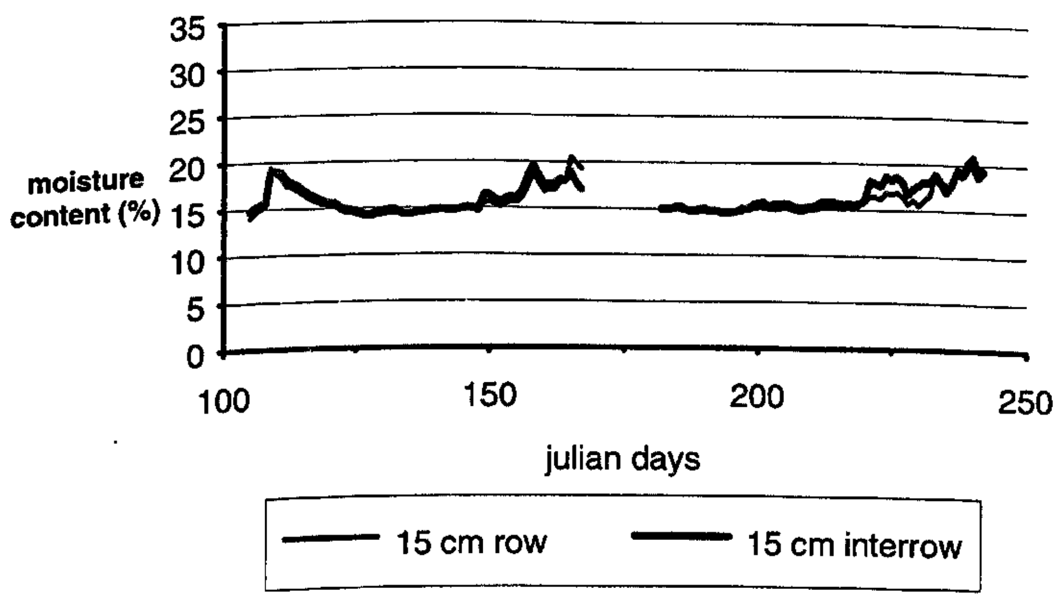
Appendix 2.7 Moisture content; Experiments 3 and 4; compartment: 14



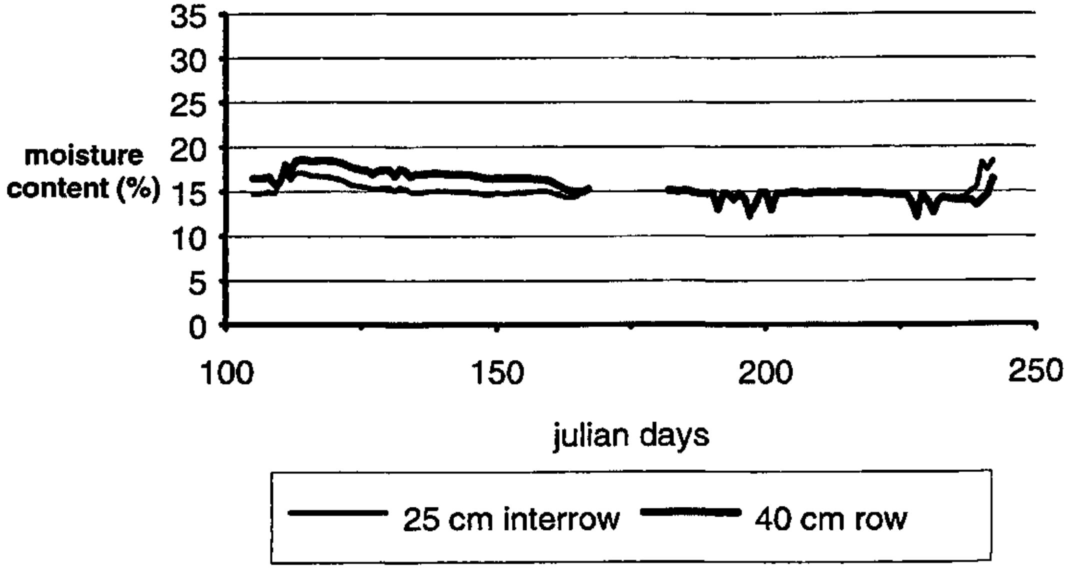


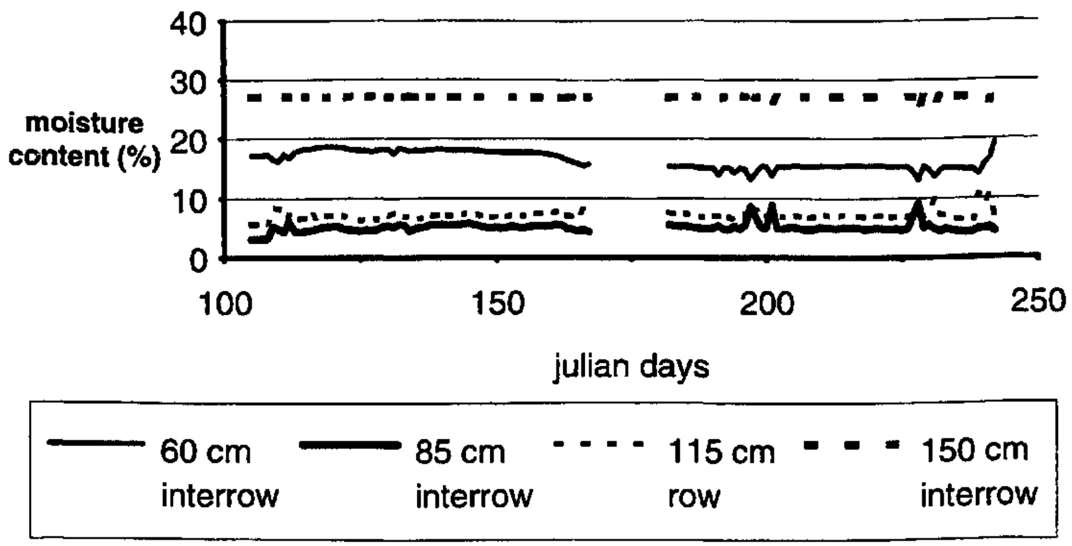
Appendix 2.7 Moisture content; Experiments 3 and 4; compartment: 14





Appendix 2.8 Moisture content; Experiments 3 and 4; compartment: 16





Appendix 2.8 Moisture content; Experiments 3 and 4; compartment: 16

Appendix III:
Root length densities (cores)

Appendix 3 Root length densities (cm cm^{-3}) assessed in core samples circa 9 weeks after planting

experiment	treatment*	lateral distance (cm)	depth (cm) 0-10	10-20	20-30	30-40	40-50	50-60	60-70
1	C	0	4.60	1.53	1.35	1.21	1.03	0.44	0.30
		15	1.85	0.72	1.15	0.72	0.93	0.59	0.72
		30	1.98	1.34	1.56	1.21	0.65	0.91	0.50
	IR	0	3.52	1.47	0.87	0.47	0.29	0.21	0.08
		15	2.37	1.72	0.79	0.62	0.27	0.32	0.30
		30	3.71	1.89	1.19	0.77	0.36	0.48	0.26
	B	0	4.41	2.24	1.17	0.63	0.57	0.18	0.40
		15	0.85	0.74	1.17	0.69	0.39	0.31	0.31
		30	0.42	0.84	1.05	0.51	0.39	0.25	0.15
	R	0	6.83	2.22	1.07	0.43	0.23	0.15	0.07
		15	2.22	1.43	1.29	0.35	0.52	0.23	0.10
		30	1.58	1.43	1.84	0.88	0.45	0.55	0.39
2	C	0	6.02	2.18	2.20	0.87	0.69	1.38	0.74
		15	3.34	2.76	2.24	0.97	0.80	1.75	1.79
		30	2.80	2.83	1.12	1.65	1.00	1.37	1.67
	IR	0	5.69	1.79	1.73	1.36	1.56	0.89	0.97
		15	2.61	2.22	1.61	1.50	0.88	0.82	0.93
		30	5.27	5.98	1.84	0.77	1.35	0.54	1.56
	B	0	7.31	2.38	1.42	1.39	0.76	0.95	0.91
		15	2.58	3.22	1.93	1.24	0.86	1.16	1.90
		30	4.09	2.84	1.83	1.04	1.12	1.37	0.95
	R	0	9.34	2.29	2.48	1.33	0.91	0.78	1.06
		15	1.69	2.83	0.97	0.65	0.93	1.24	1.18
		30	1.41	2.17	2.03	0.90	0.96	0.97	0.75
3	C	0	2.57	1.61	1.80	1.20	0.95	0.83	0.72
		15	0.86	1.93	2.47	1.34	0.85	0.75	0.38
		30	0.47	1.32	2.12	1.27	0.85	0.99	0.77
	IR	0	3.27	1.75	1.55	1.27	0.91	0.90	0.32
		15	0.57	1.69	1.45	1.25	0.77	0.43	0.21
		30	0.94	1.35	1.61	1.39	0.60	0.60	0.53
	B	0	3.73	2.36	1.28	1.34	0.51	0.15	0.35
		15	0.55	1.75	1.54	1.43	1.23	0.63	0.67
		30	0.35	1.14	1.53	1.18	0.97	0.30	0.28
	R	0	4.86	3.36	2.96	2.31	1.32	0.64	0.51
		15	0.84	2.64	1.85	1.37	0.74	0.71	0.40
		30	0.15	1.16	1.64	0.89	0.54	0.48	0.27
4	C	0	2.81	2.00	1.90	0.80	0.35	0.28	0.25
		15	1.00	1.43	1.35	0.23	0.34	0.48	0.18
		30	0.66	2.03	1.39	1.11	0.45	0.64	0.37
	IR	0	2.88	2.20	1.28	0.89	0.59	0.64	0.78
		15	1.64	1.47	1.74	1.37	0.39	0.65	0.41
		30	0.91	0.99	1.53	0.56	0.38	0.57	0.76
	B	0	3.80	2.88	2.17	0.83	0.32	0.33	0.42
		15	1.22	1.66	1.35	1.75	0.69	0.70	0.73
		30	0.64	1.87	1.28	0.69	0.95	1.11	0.77
	R	0	4.87	1.48	1.25	1.03	0.61	0.38	0.33
		15	1.92	1.86	1.12	1.25	0.87	0.56	0.17
		30	0.81	1.59	1.69	0.72	0.35	0.23	0.23

* C=control, IR=placed fertilizer in between the rows, B=broadcast fertilizer, R=placed fertilizer next to the row

Appendix IV: Root length densities (minirhizotron)

Appendix 4.1 Root density (cm cm^{-3}), Experiment 1, date: 8-5-92, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.05	0.04	0.00	0.08	0.12
10	0.10	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.2 Root density (cm cm^{-3}), Experiment 1, date: 8-5-92, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.00	0.07	0.05	0.00	0.06
10	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.3 Root density (cm cm^{-3}), Experiment 1, date: 8-5-92, treatment: row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.05	0.00	0.00	0.04	0.06
10	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.4 Root density (cm cm^{-3}), Experiment 1, date: 21-5-92, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.48	0.11	0.05	0.04	0.18
10	0.43	0.53	0.05	0.00	0.00
15	0.34	0.04	0.07	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.5 Root density (cm cm^{-3}), Experiment 1, date: 21-5-92, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.14	0.13	0.10	0.00	0.00
10	0.00	0.11	0.12	0.00	0.00
15	0.00	0.13	0.07	0.00	0.00
20	0.00	0.00	0.00	0.04	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.6 Root density (cm cm^{-3}), Experiment 1, date: 21-5-92, treatment: broadcast application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.05	0.02	0.00	1.17	0.06
10	1.40	0.18	0.07	0.00	0.00
15	0.14	0.09	0.02	0.00	0.00
20	0.00	0.00	0.05	0.00	0.00
30	0.00	0.02	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.7 Root density (cm cm^{-3}), Experiment 1, date: 21-5-92, treatment: row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.72	0.02	0.00	0.08	0.00
10	0.97	0.50	0.10	0.00	0.00
15	0.00	0.00	0.02	0.00	0.00
20	0.00	0.02	0.00	0.00	0.00
30	0.00	0.07	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.8 Root density (cm cm^{-3}), Experiment 1, date: 4-6-92, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.58	0.75	0.41	0.00	0.00
10	0.58	0.75	0.07	0.16	0.00
15	0.72	0.18	0.19	0.00	0.00
20	0.10	0.04	0.17	0.00	0.00
30	0.29	0.02	0.05	0.24	0.06
45	0.00	0.11	0.00	0.00	0.78
60	0.05	0.00	0.00	0.00	0.00

Appendix 4.9 Root density (cm cm^{-3}), Experiment 1, date: 4-6-92, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	1.45	0.88	0.24	0.00	0.12
10	0.53	0.44	0.27	0.00	0.00
15	0.53	0.68	0.65	1.33	1.27
20	1.01	0.50	0.24	0.56	0.06
30	0.00	0.02	0.17	0.12	0.12
45	0.00	0.11	0.07	0.04	0.00
60	0.00	0.00	0.07	0.08	0.00

Appendix 4.10 Root density (cm cm^{-3}), Experiment 1, date: 4-6-92, treatment: broadcast application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	3.43	0.86	0.07	1.57	0.48
10	1.50	0.57	0.41	0.04	0.00
15	0.48	0.22	0.24	0.00	0.00
20	0.19	0.26	0.53	0.08	0.00
30	0.00	0.11	0.07	0.24	0.00
45	0.00	0.00	0.02	0.00	0.00
60	0.00	0.00	0.02	0.00	0.12

Appendix 4.11 Root density (cm cm^{-3}), Experiment 1, date: 4-6-92, treatment: row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	2.03	0.50	0.02	0.04	0.00
10	4.83	3.18	0.77	0.08	0.00
15	0.10	0.22	0.05	0.00	0.00
20	0.29	0.22	0.29	0.12	0.00
30	0.00	0.22	0.12	0.00	0.00
45	0.00	0.07	0.00	0.20	0.30
60	0.00	0.02	0.12	0.00	0.00

Appendix 4.12 Root density (cm cm^{-3}), Experiment 1, date: 16-6-92, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	1.55	2.72	1.11	1.61	0.97
10	1.06	1.36	0.29	0.24	0.00
15	0.97	0.31	0.43	0.08	0.36
20	0.58	0.59	0.46	0.08	0.24
30	0.48	0.33	0.51	0.76	0.60
45	0.29	0.15	0.07	0.04	1.09
60	0.05	0.07	0.05	0.00	0.00

Appendix 4.13 Root density (cm cm^{-3}), Experiment 1, date: 16-6-92, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	2.80	2.85	1.50	1.29	2.05
10	1.06	0.83	0.29	0.24	0.24
15	0.48	1.19	1.30	1.93	2.29
20	1.06	0.72	0.56	0.56	0.42
30	0.05	0.09	0.34	0.32	0.18
45	0.00	0.18	0.24	0.04	0.00
60	0.05	0.00	0.10	0.28	0.00

Appendix 4.14 Root density (cm cm^{-3}), Experiment 1, date: 16-6-92, treatment: broadcast application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	6.76	5.79	1.79	0.16	0.24
10	1.64	1.36	0.68	0.72	0.24
15	0.63	0.50	0.75	0.08	0.12
20	0.58	0.72	0.85	0.52	0.30
30	0.19	0.33	0.46	0.48	0.00
45	0.14	0.00	0.02	0.04	0.06
60	0.00	0.11	0.05	0.20	0.72

Appendix 4.15 Root density (cm cm^{-3}), Experiment 1, date: 16-6-92, treatment: row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	6.08	2.55	2.03	0.56	0.36
10	5.41	4.57	1.69	0.72	0.00
15	1.45	1.10	0.05	0.00	0.00
20	0.68	0.42	0.41	0.16	0.00
30	0.00	0.37	0.10	0.00	0.06
45	0.00	0.09	0.02	0.24	0.78
60	0.00	0.04	0.34	0.00	0.00

Appendix 4.16 Root density (cm cm^{-3}), Experiment 1, date: 22-6-92, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	1.55	2.72	1.16	1.77	1.33
10	1.55	1.67	0.19	0.32	0.12
15	1.84	0.40	0.63	0.24	1.09
20	0.68	1.01	0.72	0.24	0.60
30	0.53	0.55	0.89	0.89	1.03
45	0.43	0.13	0.19	0.12	1.03
60	0.24	0.13	0.14	0.08	0.18

Appendix 4.17 Root density (cm cm^{-3}), Experiment 1, date: 22-6-92, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	3.09	2.77	1.55	1.85	2.90
10	1.16	1.23	0.29	0.24	1.21
15	0.97	1.19	1.64	2.82	3.26
20	1.74	0.75	0.82	0.48	0.97
30	0.10	0.26	0.87	0.64	0.42
45	0.19	0.31	0.34	0.08	0.06
60	0.10	0.00	0.14	0.16	0.12

Appendix 4.18 Root density (cm cm^{-3}), Experiment 1, date: 22-6-92, treatment: broadcast application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	6.37	7.11	3.04	0.24	1.09
10	2.03	1.32	0.58	1.05	0.36
15	1.06	0.40	0.87	0.00	0.36
20	0.58	0.97	0.77	0.80	0.48
30	0.24	0.40	0.60	0.76	0.24
45	0.19	0.07	0.02	0.08	0.24
60	0.19	0.09	0.17	0.32	0.54

Appendix 4.19 Root density (cm cm^{-3}), Experiment 1, date: 22-6-92, treatment: row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	6.95	6.19	2.75	2.82	1.21
10	6.76	5.49	2.17	1.21	0.12
15	2.03	1.71	0.24	0.32	0.24
20	0.58	0.92	0.58	0.32	0.24
30	0.00	0.37	0.27	0.20	0.12
45	0.05	0.15	0.05	0.32	1.21
60	0.05	0.07	0.51	0.04	0.06

Appendix 4.20 Root density (cm cm^{-3}), Experiment 2, 16-7-92, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.98	0.21	0.00	0.00	0.00
10	1.58	0.03	0.04	0.00	0.00
15	0.00	0.03	0.34	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.21 Root density (cm cm^{-3}), Experiment 2, date: 16-7-92, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.53	0.27	0.00	0.19	0.00
10	0.98	0.51	0.49	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.22 Root density (cm cm^{-3}), Experiment 2, date: 16-7-92, treatment: broadcast application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	1.50	0.65	0.11	0.13	0.00
10	0.00	0.44	0.04	0.00	0.00
15	0.08	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.23 Root density (cm cm^{-3}), Experiment 2, date: 16-7-92, treatment: row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	2.48	1.44	0.23	0.00	0.00
10	0.23	0.48	0.00	0.00	0.00
15	0.00	0.10	0.04	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.24 Root density (cm cm^{-3}), Experiment 2, 23-7-92, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	1.58	1.40	1.43	0.00	0.00
10	1.58	0.07	0.19	1.07	0.09
15	0.30	0.10	0.68	0.00	0.00
20	0.00	0.07	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.25 Root density (cm $^{-3}$), Experiment 2, date: 23-7-92, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	1.28	0.58	0.04	0.06	0.00
10	1.05	0.62	1.02	0.25	0.00
15	0.00	0.03	0.15	0.06	0.00
20	0.00	0.00	0.04	0.00	0.00
30	0.00	0.00	0.45	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.26 Root density (cm cm $^{-3}$), Experiment 2, date: 23-7-92, treatment: broadcast application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	3.23	2.02	0.90	0.00	0.00
10	0.30	0.62	0.71	0.06	0.00
15	0.90	0.27	0.04	0.75	0.28
20	0.00	0.00	0.00	0.00	0.00
30	0.45	0.14	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.27 Root density (cm cm $^{-3}$), Experiment 2, date: 23-7-92, treatment: row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	3.08	2.53	1.50	0.00	0.00
10	1.43	0.27	0.19	0.00	0.00
15	0.00	0.34	0.38	0.13	0.00
20	0.00	0.00	0.23	0.06	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.28 Root density (cm cm^{-3}), Experiment 2, date: 6-8-92, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	2.48	2.19	1.54	0.00	0.00
10	1.73	2.32	2.63	4.89	3.57
15	0.98	1.40	1.02	1.63	2.63
20	0.08	0.27	0.45	0.44	0.28
30	0.08	0.07	1.05	0.75	0.09
45	0.00	0.41	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.29 Root density (cm cm^{-3}), Experiment 2, date: 6-8-92, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	2.33	1.13	1.50	1.13	0.47
10	1.96	2.56	2.44	1.75	3.29
15	1.65	1.78	2.71	1.63	1.50
20	0.30	0.27	0.60	0.44	0.75
30	0.38	0.68	1.05	0.00	0.28
45	0.00	0.00	0.08	0.00	0.00
60	0.00	0.03	0.00	0.00	0.00

Appendix 4.30 Root density (cm cm^{-3}), Experiment 2, date: 6-8-92, treatment: broadcast application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	6.32	3.90	3.08	0.63	1.03
10	0.75	1.47	2.90	1.88	0.94
15	2.86	3.52	2.71	4.14	4.32
20	0.60	0.38	1.39	0.31	0.28
30	0.60	0.82	1.05	0.00	0.00
45	0.15	0.14	0.08	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.31 Root density (cm cm^{-3}), Experiment 2, date: 6-8-92, treatment: row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	7.52	4.38	4.06	3.01	0.56
10	3.76	2.36	2.52	0.44	2.26
15	0.83	1.68	3.38	2.70	4.61
20	0.08	0.48	2.03	2.01	0.56
30	0.15	0.34	0.04	0.06	0.56
45	0.23	0.00	0.11	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.32 Root density (cm cm^{-3}), Experiment 2, date: 20-8-92, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	3.46	2.12	1.35	0.00	0.00
10	2.56	3.49	2.48	4.64	3.57
15	1.50	2.87	2.26	1.75	3.38
20	1.50	1.64	2.18	1.25	0.75
30	0.60	1.03	2.18	0.75	0.56
45	1.20	0.62	1.20	0.63	0.94
60	0.38	0.07	0.94	1.00	0.85

Appendix 4.33 Root density (cm cm^{-3}), Experiment 2, date: 20-8-92, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	1.65	1.44	2.18	1.75	1.32
10	3.46	2.39	1.50	1.50	1.88
15	2.71	3.21	2.71	1.13	2.07
20	2.26	1.50	1.20	1.50	3.20
30	1.96	1.57	1.65	0.50	0.56
45	0.15	0.58	0.45	0.00	0.00
60	0.23	0.31	0.68	0.19	0.00

Appendix 4.34 Root density (cm cm^{-3}), Experiment 2, date: 20-8-92, treatment: broadcast application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	5.57	3.69	2.11	0.75	1.13
10	2.71	1.71	3.16	2.01	0.75
15	2.71	3.69	3.38	3.64	3.95
20	2.56	2.12	1.96	0.50	0.75
30	2.11	2.46	1.96	1.25	0.00
45	0.45	0.82	0.38	1.00	0.19
60	0.30	0.41	0.11	0.19	0.00

Appendix 4.35 Root density (cm cm^{-3}), Experiment 2, date: 20-8-92, treatment: row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	6.77	3.42	2.41	2.26	0.75
10	3.46	1.91	2.41	0.25	1.13
15	2.26	2.67	2.33	3.01	5.45
20	2.56	2.74	3.38	2.63	1.32
30	1.35	2.12	1.35	1.13	1.69
45	1.35	1.37	2.26	1.00	0.75
60	0.98	0.48	0.41	1.19	0.94

Appendix 4.36 Root density (cm cm^{-3}), Experiment 2, date: 31-8-92, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	3.16	1.37	0.98	0.00	0.00
10	3.76	3.62	2.86	4.26	2.82
15	1.81	2.80	2.41	2.26	3.95
20	1.81	2.12	2.03	1.00	0.38
30	1.05	1.23	2.41	1.00	0.38
45	1.96	0.89	1.50	2.01	1.32
60	0.30	0.62	1.50	1.63	1.50

Appendix 4.37 Root density (cm cm^{-3}), Experiment 2, date: 31-8-92, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	1.96	1.30	2.41	1.75	1.13
10	3.61	2.60	1.96	1.50	3.20
15	3.46	3.08	3.08	1.13	2.63
20	2.41	1.98	1.20	1.38	3.76
30	1.35	2.32	1.81	0.50	0.56
45	0.60	0.75	0.53	0.00	0.00
60	0.30	0.62	1.05	0.75	0.00

Appendix 4.38 Root density (cm cm^{-3}), Experiment 2, date: 31-8-92, treatment: broadcast application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	6.17	4.38	1.81	0.63	1.13
10	3.16	2.87	3.23	2.01	0.94
15	2.71	4.85	3.69	3.76	5.45
20	2.26	2.05	2.78	0.75	0.75
30	2.26	2.53	2.03	1.75	0.56
45	0.45	1.09	1.20	1.50	0.38
60	1.20	0.89	0.53	0.25	0.00

Appendix 4.39 Root density (cm cm^{-3}), Experiment 2, date: 31-8-92, treatment: row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	10.68	4.99	2.78	2.38	0.94
10	5.26	2.32	2.63	0.50	1.50
15	2.11	3.49	3.23	4.14	5.64
20	4.06	3.97	3.99	2.63	0.94
30	1.81	2.80	1.20	1.50	2.44
45	1.81	1.98	2.03	1.38	0.94
60	1.81	1.03	1.58	1.88	1.69

Appendix 4.40 Root density (cm cm^{-3}), Experiment 3, date: 29-4-93, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.04	0.00	0.02	0.04	0.00
10	0.04	0.13	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.41 Root density (cm cm^{-3}), Experiment 3, date: 29-4-93, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.04	0.02	0.00	0.04	0.11
10	0.13	0.08	0.02	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.42 Root density (cm cm^{-3}), Experiment 3, date: 29-4-93, treatment: broadcast application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.00	0.08	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.43 Root density (cm cm^{-3}), Experiment 3, date: 29-4-93, treatment: row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.04	0.00	0.04	0.00	0.00
10	0.00	0.06	0.04	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.44 Root density (cm cm^{-3}), Experiment 3, date: 7-5-93, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.59	0.02	0.13	0.11	0.00
10	0.21	0.52	0.04	0.04	0.00
15	0.00	0.00	0.02	0.00	0.00
20	0.00	0.10	0.06	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.45 Root density (cm cm^{-3}), Experiment 3, date: 7-5-93, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.21	0.10	0.00	0.25	0.16
10	0.25	0.39	0.08	0.00	0.00
15	0.00	0.08	0.11	0.00	0.00
20	0.00	0.00	0.02	0.00	0.11
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.46 Root density (cm cm^{-3}), Experiment 3, date: 19-5-93, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	2.03	0.31	0.25	0.00	0.00
10	0.59	1.04	0.25	0.00	0.00
15	0.08	0.19	0.13	0.14	0.42
20	0.17	0.65	0.25	0.00	0.64
30	0.17	0.06	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.47 Root density (cm cm^{-3}), Experiment 3, date: 19-5-93, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.93	0.23	0.00	0.14	0.32
10	0.68	0.65	0.30	0.07	0.00
15	0.34	0.65	0.21	0.07	0.11
20	0.25	0.00	0.04	0.35	0.74
30	0.08	0.04	0.08	0.00	0.00
45	0.08	0.02	0.06	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.48 Root density (cm cm^{-3}), Experiment 3, date 19-5-93:, treatment: broadcast application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	1.36	1.77	0.72	0.00	0.00
10	1.70	0.58	0.38	0.00	0.00
15	0.68	0.23	0.38	0.42	0.00
20	0.08	0.19	0.04	0.21	0.00
30	0.00	0.04	0.00	0.00	0.00
45	0.00	0.04	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.49 Root density (cm cm^{-3}), Experiment 3, date 19-5-93:, treatment: row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	3.05	0.89	0.08	0.00	0.00
10	0.59	0.85	0.51	0.28	0.00
15	0.51	0.92	0.17	0.07	0.00
20	0.42	0.27	0.08	0.42	2.12
30	0.00	0.17	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.50 Root density (cm cm^{-3}), Experiment 3, date 4-6-93:, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	3.14	1.70	0.34	0.00	0.00
10	1.53	2.43	1.40	0.28	0.00
15	1.02	0.89	0.55	0.14	0.95
20	0.68	1.43	0.68	0.71	1.38
30	0.25	0.15	0.30	0.71	0.74
45	0.25	0.04	0.13	0.07	0.00
60	0.04	0.04	0.36	0.04	0.00

Appendix 4.51 Root density (cm cm^{-3}), Experiment 3, date 4-6-93:, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	2.71	0.39	0.00	0.14	0.21
10	0.93	1.43	0.59	0.07	0.00
15	0.93	1.04	0.30	0.21	0.11
20	1.27	0.65	0.85	0.71	1.17
30	0.51	0.96	0.51	0.78	0.32
45	0.08	0.73	0.47	0.07	0.00
60	0.00	0.00	0.11	0.00	0.00

Appendix 4.52 Root density (cm cm^{-3}), Experiment 3, date: 4-6-93, treatment: broadcast application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	1.70	1.85	0.47	0.00	0.00
10	3.14	1.66	0.72	0.14	0.00
15	0.93	1.19	0.55	0.35	0.11
20	0.68	0.73	1.65	0.42	0.42
30	0.08	0.46	0.17	0.64	0.85
45	0.25	0.15	0.25	0.07	0.64
60	0.00	0.04	0.11	0.07	0.00

Appendix 4.53 Root density (cm cm^{-3}), Experiment 3, date 4-6-93:, treatment: row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	3.47	1.19	0.13	0.00	0.00
10	3.47	1.19	0.89	0.64	0.42
15	1.27	1.66	0.81	0.49	0.32
20	0.85	1.04	1.06	0.57	2.12
30	0.59	1.23	1.23	0.21	2.44
45	0.00	0.42	0.13	0.49	0.11
60	0.08	0.02	0.06	0.00	0.00

Appendix 4.54 Root density (cm cm^{-3}), Experiment 3, date: 14-6-93, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	2.71	1.93	0.59	0.00	0.00
10	1.44	2.58	2.25	0.35	0.00
15	1.86	1.39	0.38	0.35	1.06
20	1.78	2.39	1.27	1.62	2.01
30	0.76	0.85	0.85	1.91	1.70
45	0.85	0.54	0.42	0.35	0.11
60	0.42	0.31	0.72	0.21	0.21

Appendix 4.55 Root density (cm cm^{-3}), Experiment 3, date: 14-6-93, treatment: control (right side)

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	2.54	1.70	0.89	0.71	0.64
10	1.86	1.77	0.97	1.70	1.27
15	1.86	1.66	1.91	0.71	1.06
20	1.70	1.70	1.02	1.48	1.27
30	1.19	1.19	1.36	0.35	1.06
45	0.34	0.50	0.38	0.14	0.00
60	0.68	0.65	0.89	0.49	0.85

Appendix 4.56 Root density (cm cm^{-3}), Experiment 3, date: 14-6-93, treatment: control (left side)

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	1.70	2.23	1.23	0.21	0.42
10	1.27	1.89	1.19	0.64	1.06
15	1.70	1.70	1.27	0.42	1.17
20	1.78	1.50	1.78	0.64	0.32
30	1.02	1.27	1.06	2.26	0.74
45	0.59	0.50	0.59	0.78	0.42
60	0.51	0.27	0.08	0.00	0.00

Appendix 4.57 Root density (cm cm^{-3}), Experiment 3, date: 14-6-93, treatment: control (bottom side)

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.51	1.89	1.74	1.34	1.59
10	1.10	1.39	1.82	1.41	2.12
15	1.36	1.27	1.48	2.19	4.56
20	0.76	1.12	1.14	1.77	0.74
30	0.85	0.96	1.10	1.20	2.01
45	0.42	0.50	0.42	0.00	0.11
60	0.00	0.23	0.85	0.21	0.11

Appendix 4.58 Root density (cm cm^{-3}), Experiment 3, date: 14-6-93, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	2.54	0.65	0.25	0.00	0.21
10	1.53	1.50	0.89	0.07	0.00
15	2.12	1.43	0.34	0.57	0.53
20	2.54	1.08	1.48	0.99	1.80
30	0.93	1.73	0.68	0.78	0.85
45	0.68	1.08	0.34	0.21	0.11
60	0.34	0.27	0.55	0.14	0.00

Appendix 4.59 Root density (cm cm^{-3}), Experiment 3, date: 14-6-93, treatment: inter row application (right side)

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	5.00	1.73	0.85	0.00	0.32
10	1.44	1.04	1.02	0.49	1.91
15	1.44	1.70	0.81	0.85	0.74
20	1.10	1.58	1.31	1.06	1.17
30	2.20	2.39	2.16	0.85	1.38
45	0.76	0.65	0.51	0.57	0.11
60	0.51	1.46	0.72	0.64	1.38

Appendix 4.60 Root density (cm cm^{-3}), Experiment 3, date: 14-6-93, treatment: inter row application (left side)

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	1.86	1.00	0.17	0.42	0.11
10	1.61	1.54	0.81	0.85	0.85
15	1.61	1.89	1.27	1.77	1.17
20	0.76	2.47	1.10	1.48	2.22
30	0.42	0.96	1.06	0.92	1.06
45	0.93	0.85	0.51	0.42	0.32
60	1.19	0.46	0.76	0.00	0.11

Appendix 4.61 Root density (cm cm^{-3}), Experiment 3, date: 14-6-93, treatment: inter row application (bottom side)

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	1.61	1.62	1.10	0.92	0.74
10	0.68	0.77	1.14	2.12	1.91
15	0.93	0.85	1.82	3.18	2.22
20	0.34	0.96	0.38	1.34	2.44
30	0.85	0.81	0.72	1.48	0.21
45	0.42	0.00	0.04	0.07	0.11
60	0.00	0.08	0.13	0.14	0.32

Appendix 4.62 Root density (cm cm^{-3}), Experiment 3, date: 14-6-93, treatment: broadcast application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	2.20	1.85	0.42	0.00	0.11
10	3.90	1.85	1.10	0.64	0.00
15	1.86	1.27	0.72	0.42	0.32
20	1.44	1.54	2.33	0.85	0.85
30	0.51	0.81	0.64	0.78	1.70
45	0.42	0.62	0.81	0.28	0.85
60	0.08	0.19	0.30	0.21	0.00

Appendix 4.63 Root density (cm cm^{-3}), Experiment 3, date: 14-6-93, treatment: broadcast application (right side)

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	4.07	2.04	1.57	1.55	0.95
10	2.12	1.96	0.81	0.49	0.00
15	1.44	1.62	0.85	1.34	2.12
20	1.61	1.73	1.70	1.62	1.91
30	1.53	2.85	1.10	0.42	1.17
45	0.68	0.19	0.68	0.92	0.74
60	0.25	0.65	0.34	0.71	0.00

Appendix 4.64 Root density (cm cm^{-3}), Experiment 3, date: 14-6-93, treatment: broadcast application (left side)

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	2.80	2.00	1.91	1.62	0.32
10	1.78	1.70	1.40	1.91	0.85
15	1.61	0.89	0.68	0.07	0.64
20	1.27	0.92	0.72	2.75	3.07
30	1.10	1.08	1.23	1.34	0.64
45	0.42	0.46	1.10	0.49	2.22
60	0.34	0.50	0.13	0.00	0.11

Appendix 4.65 Root density (cm cm^{-3}), Experiment 3, date: 14-6-93, treatment: broadcast application (bottom side)

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	1.78	1.19	1.14	1.41	2.22
10	0.17	1.08	1.40	1.70	1.59
15	0.85	1.31	1.10	1.27	1.38
20	0.00	0.89	1.19	1.84	1.80
30	1.27	0.96	0.68	0.49	0.74
45	0.08	0.04	0.34	0.85	0.95
60	0.25	0.54	0.30	0.07	0.00

Appendix 4.66 Root density (cm cm^{-3}), Experiment 3, date: 14-6-93, treatment: row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	5.51	1.77	0.34	0.35	0.21
10	3.64	3.16	1.02	0.78	0.21
15	2.80	2.39	1.57	2.26	1.38
20	2.03	2.20	2.50	1.62	3.60
30	1.27	2.20	2.92	1.98	3.39
45	0.25	0.46	1.19	1.06	0.64
60	0.76	0.27	0.30	0.00	0.11

Appendix 4.67 Root density (cm cm^{-3}), Experiment 3, date: 14-6-93, treatment: row application (right side)

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	5.17	2.97	0.72	0.14	0.11
10	2.29	1.62	2.54	2.40	2.22
15	1.86	1.04	1.23	3.25	2.86
20	1.44	2.35	1.48	1.06	1.17
30	0.42	2.50	2.54	1.77	2.33
45	0.85	1.19	0.68	0.85	0.74
60	0.68	0.65	0.42	2.12	0.42

Appendix 4.68 Root density (cm cm^{-3}), Experiment 3, date: 14-6-93, treatment: row application (left side)

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	6.86	3.47	1.74	1.06	2.97
10	2.03	1.77	1.06	0.35	0.74
15	1.78	2.39	2.08	1.27	1.06
20	1.86	2.62	1.95	1.27	1.80
30	0.93	1.77	2.54	1.62	1.17
45	0.00	0.58	1.02	1.27	0.11
60	0.76	0.39	0.85	0.07	0.11

Appendix 4.69 Root density (cm cm^{-3}), Experiment 3, date: 14-6-93, treatment: row application (bottom side)

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	1.27	1.35	1.65	1.55	0.42
10	0.93	1.23	1.53	1.77	2.54
15	0.85	0.92	0.97	2.05	2.01
20	1.19	1.04	2.20	2.97	2.75
30	0.17	0.23	0.72	1.34	0.64
45	0.59	0.23	0.25	0.42	0.64
60	0.34	0.23	0.17	0.28	0.00

Appendix 4.70 Root density (cm cm^{-3}), Experiment 4, date: 15-7-93, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.82	0.89	0.10	0.00	0.00
10	0.10	0.05	0.00	0.00	0.00
15	0.00	0.02	0.03	0.09	0.00
20	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.71 Root density (cm cm^{-3}), Experiment 4, date: 15-7-93, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.41	0.42	0.00	0.00	0.00
10	0.31	0.28	0.00	0.00	0.00
15	0.00	0.00	0.08	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
30	0.10	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.72 Root density (cm cm^{-3}), Experiment 4, date: 15-7-93, treatment: broadcast application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	2.27	0.52	0.00	0.00	0.00
10	0.72	0.33	0.05	0.00	0.00
15	0.00	0.05	0.00	0.00	0.26
20	0.00	0.05	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.73 Root density (cm cm^{-3}), Experiment 4, date: 15-7-93, treatment: row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.93	0.14	0.00	0.00	0.00
10	1.03	0.14	0.00	0.00	0.00
15	0.10	0.00	0.00	0.09	0.00
20	0.00	0.00	0.00	0.09	0.00
30	0.00	0.05	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.74 Root density (cm cm^{-3}), Experiment 4, date: 27-7-93, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	2.06	2.06	0.21	0.09	0.00
10	0.31	0.09	0.10	0.00	0.00
15	0.00	0.23	0.21	0.17	0.77
20	0.10	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.75 Root density (cm cm^{-3}), Experiment 4, date: 27-7-93, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	1.34	0.89	0.10	0.00	0.00
10	0.82	0.80	0.15	0.00	0.00
15	0.00	0.09	0.67	0.43	0.64
20	0.00	0.00	0.00	0.00	0.64
30	0.31	0.23	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.76 Root density (cm cm^{-3}), Experiment 4, date: 27-7-93, treatment: broadcast application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	1.75	0.94	0.00	0.00	0.00
10	0.31	0.84	0.21	0.09	0.00
15	0.21	0.61	0.21	0.09	0.64
20	0.00	0.28	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.77 Root density (cm cm^{-3}), Experiment 4, date: 27-7-93, treatment: row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	3.71	1.69	0.10	0.00	0.00
10	1.65	0.66	0.21	0.00	0.00
15	0.52	0.19	0.31	0.69	0.13
20	0.00	0.28	0.21	0.00	0.13
30	0.00	0.00	0.21	0.09	0.13
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.78 Root density (cm cm^{-3}), Experiment 4, date: 12-8-93, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	3.71	2.29	0.88	1.20	1.67
10	1.03	0.66	0.46	0.00	0.00
15	0.41	0.98	0.57	0.34	0.90
20	0.21	0.14	0.31	1.20	0.77
30	0.10	0.00	0.10	0.26	0.13
45	0.10	0.19	0.15	0.00	0.26
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.79 Root density (cm cm^{-3}), Experiment 4, date: 12-8-93, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	2.27	1.22	0.31	0.26	0.77
10	1.03	0.84	0.41	0.17	0.64
15	1.44	0.80	1.13	1.20	0.52
20	0.00	0.37	0.98	1.12	1.80
30	0.93	1.08	0.52	0.69	1.16
45	0.31	0.19	0.15	0.00	0.13
60	0.00	0.02	0.33	0.00	0.00

Appendix 4.80 Root density (cm cm^{-3}), Experiment 4, date: 12-8-93, treatment: broadcast application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	2.06	1.64	0.00	0.34	0.00
10	1.24	0.94	0.72	0.26	0.00
15	2.27	0.98	0.41	0.26	0.52
20	0.00	0.56	0.26	0.00	0.13
30	0.00	0.33	0.15	0.09	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.81 Root density (cm cm^{-3}), Experiment 4, date: 12-8-93, treatment: row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	4.02	3.00	0.57	0.43	0.00
10	2.58	1.22	0.67	0.17	0.00
15	0.62	0.37	0.57	3.09	0.90
20	0.41	1.73	1.03	0.69	1.16
30	0.10	0.19	0.77	0.09	0.26
45	0.00	0.07	0.00	0.00	0.00
60	0.00	0.00	0.00	0.17	0.00

Appendix 4.82 Root density (cm cm^{-3}), Experiment 4, date: 31-8-93, treatment: control

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	3.61	2.58	1.34	1.55	1.67
10	1.44	1.08	0.46	0.34	0.26
15	1.24	2.01	0.67	0.60	1.16
20	1.24	1.08	0.72	1.55	1.16
30	1.13	0.42	0.62	0.69	0.26
45	0.31	0.52	0.26	0.00	0.52
60	0.10	0.47	0.31	0.26	0.26

Appendix 4.83 Root density (cm cm^{-3}), Experiment 4, date: 31-8-93, treatment: inter row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	2.78	1.26	0.88	0.77	1.80
10	2.06	1.50	0.52	0.60	1.55
15	2.06	1.40	1.44	0.94	0.52
20	0.82	1.17	0.88	1.20	3.35
30	1.13	1.78	1.55	1.37	1.93
45	1.03	0.80	0.93	0.00	0.52
60	0.93	0.89	0.93	0.09	0.00

Appendix 4.84 Root density (cm cm^{-3}), Experiment 4, date: 31-8-93, treatment: broadcast application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	3.09	2.58	0.00	0.60	0.26
10	1.85	1.40	0.88	0.34	0.00
15	3.50	1.64	0.52	0.60	0.90
20	0.82	1.31	0.67	0.00	0.64
30	0.72	0.84	1.13	0.86	0.52
45	0.72	0.75	0.88	0.94	0.13
60	0.41	0.75	0.72	0.00	0.00

Appendix 4.85 Root density (cm cm^{-3}), Experiment 4, date: 31-8-93, treatment: broadcast application (right side)

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	2.16	2.43	2.42	2.32	0.90
10	2.37	2.25	0.41	0.43	0.77
15	3.09	2.06	1.75	1.20	1.03
20	0.93	0.61	1.13	0.09	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.86 Root density (cm cm^{-3}), Experiment 4, date: 31-8-93, treatment: broadcast application (left side)

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	3.81	1.97	0.62	0.86	1.42
10	2.06	3.04	1.03	1.37	0.52
15	2.06	2.81	2.06	2.49	1.29
20	0.62	0.84	1.13	0.52	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.87 Root density (cm cm^{-3}), Experiment 4, date: 31-8-93, treatment: broadcast application (bottom side)

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	1.85	1.64	2.58	4.03	3.48
10	1.13	2.06	1.91	1.97	2.19
15	0.82	1.03	3.14	1.63	4.12
20	0.21	0.56	0.46	0.26	0.00
30	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00

Appendix 4.88 Root density (cm cm^{-3}), Experiment 4, date: 31-8-93, treatment: row application

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	5.46	3.84	1.13	0.52	0.00
10	3.81	1.78	0.98	0.26	0.13
15	1.55	2.01	0.72	3.00	1.16
20	1.34	2.34	1.08	1.29	2.45
30	0.52	1.40	2.21	1.03	0.26
45	0.62	0.89	0.15	0.17	0.26
60	0.00	1.12	0.36	0.77	0.64

Appendix 4.89 Root density (cm cm^{-3}), Experiment 4, date: 31-8-93, treatment: row application (right side)

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	3.71	3.28	2.32	0.60	1.29
10	0.62	1.92	2.11	1.29	0.77
15	1.34	1.17	1.34	3.09	2.83
20	2.47	2.67	2.06	0.77	1.03
30	1.03	1.87	2.16	1.80	0.77
45	0.93	0.37	0.10	0.60	0.39
60	0.00	0.23	0.26	0.00	0.39

Appendix 4.90 Root density (cm cm^{-3}), Experiment 4, date: 31-8-93, treatment: row application (left side)

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	5.46	1.92	1.55	0.86	1.03
10	1.34	0.84	1.18	0.60	0.77
15	0.62	1.45	0.82	1.72	3.22
20	2.68	1.36	0.93	2.15	1.93
30	0.52	1.59	1.24	0.86	0.13
@	0.10	0.52	0.67	0.09	0.13
60	0.21	0.70	1.03	0.43	0.13

Appendix 4.91 Root density (cm cm^{-3}), Experiment 4, date: 31-8-93, treatment: row application (bottom side)

depth (cm)	distance (cm)				
	0-4	4-11	11-19	19-26	26-30
5	0.82	1.73	2.11	3.35	4.25
10	1.13	1.83	0.41	2.15	3.22
15	0.82	1.36	2.47	3.43	4.12
20	1.13	1.36	1.18	3.69	1.03
30	0.21	0.75	1.18	1.63	0.77
45	0.00	0.05	0.00	0.00	0.00
60	0.00	0.14	0.21	0.09	0.00

Appendix V: Soil mineral N

Appendix 5.1 Soil mineral N (ceramic cup and RHIZON SSS tube samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 1, control)

		date											
		21-4-92			11-5-92			1-6-92			22-6-92		
position*		r	ir	m	r	ir	m	r	ir	m	r	ir	m
layer (cm)	0 - 10	4	4	4	6	6	6	5	8	6	0	0	0
	10 - 20	5	6	6	6	7	6	4	7	6	0	0	0
	20 - 30	5	5	5	6	6	6	6	7	7	0	0	0
	30 - 50	9	9	9	10	10	10	13	13	13	11	7	9
	50 - 70	9	9	9	12	12	12	14	16	15	15	8	11
	70 -100			4			4			4			4
	100 -130			0			2			6			4
	130 -170			1			1			1			2
	0 - 20	10	10	10	11	13	12	9	15	12	0	0	0
	0 - 50	23	23	23	27	29	28	28	35	32	11	7	9
	0 - 70	32	33	32	39	41	40	42	51	47	26	15	21
	0 -170			37			47			58			30

* r=under the maize row, ir=in between the maize row, m=mean of both values (0-70 cm) or random sample (70-170 cm)

Appendix 5.2 Soil mineral N (ceramic cup and RHIZON SSS tube samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 1, placed fertilizer in between the rows)

		date											
		21-4-92			11-5-92			1-6-92			22-6-92		
position*		r	ir	m	r	ir	m	r	ir	m	r	ir	m
layer (cm)	0 - 10	8	12	10	5	4	5	65	7	36	1	1	1
	10 - 20	6	6	6	3	7	5	5	6	6	0	0	0
	20 - 30	6	5	5	7	6	7	7	6	7	0	1	1
	30 - 50	9	9	9	12	11	12	14	13	14	10	3	7
	50 - 70	9	9	9	13	13	13	16	15	15	17	10	14
	70 -100			3			4			4			4
	100 -130			0			3			2			2
	130 -170			0			17			1			2
	0 - 20	14	18	16	8	11	9	69	14	41	1	1	1
	0 - 50	28	32	30	27	28	28	91	33	62	11	6	8
	0 - 70	37	41	39	40	41	41	106	48	77	28	16	22
	0 -170			43			65			84			30

* r=under the maize row, ir=in between the maize row, m=mean of both values (0-70 cm) or random sample (70-170 cm)

Appendix 5.3 Soil mineral N (ceramic cup and RHIZON SSS tube samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 1, broadcast fertilizer)

		date											
		21-4-92			11-5-92			1-6-92			22-6-92		
position*		r	ir	m	r	ir	m	r	ir	m	r	ir	m
layer (cm)	0 - 10	34	34	34	13	20	17	3	11	7	4	23	14
	10 - 20	6	6	6	6	6	6	4	7	5	0	7	4
	20 - 30	5	5	5	6	6	6	4	8	6	0	2	1
	30 - 50	10	9	10	12	11	12	14	15	14	3	13	8
	50 - 70	10	10	10	12	12	12	15	15	15	14	12	13
	70 -100			2			4			4			2
	100 -130			1			2			3			4
	130 -170			0			1			2			2
	0 - 20	40	40	40	20	25	22	8	18	13	4	31	17
	0 - 50	54	54	54	37	42	40	26	40	33	7	46	26
	0 - 70	64	64	64	49	55	52	41	55	48	21	57	39
	0 -170			67			58			57			47

* r=under the maize row, ir=in between the maize row, m=mean of both values (0-70 cm) or random sample (70-170 cm)

Appendix 5.4 Soil mineral N (ceramic cup and RHIZON SSS tube samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 1, placed fertilizer next to the rows)

		date											
		21-4-92			11-5-92			1-6-92			22-6-92		
position*		r	ir	m	r	ir	m	r	ir	m	r	ir	m
layer (cm)	0 - 10	109	6	57	86	7	46	11	10	10	1	6	4
	10 - 20	7	5	6	7	6	7	4	8	6	0	1	1
	20 - 30	5	5	5	6	6	6	7	7	7	1	1	1
	30 - 50	11	9	10	12	12	12	15	13	14	10	9	10
	50 - 70	10	10	10	12	12	12	15	15	15	12	16	14
	70 -100			5			7			10			11
	100 -130			0			1			2			2
	130 -170			0			1			1			2
	0 - 20	116	10	63	94	12	53	15	17	16	1	7	4
	0 - 50	132	25	79	111	30	71	38	38	38	12	17	14
	0 - 70	142	35	88	123	42	83	53	53	53	24	32	28
	0 -170			94			91			66			42

* r=under the maize row, ir=in between the maize row, m=mean of both values (0-70 cm) or random sample (70-170 cm)

Appendix 5.5 Soil mineral N (ceramic cup and RHIZON SSS tube samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 2, control)

		date											
		6-7-92			20-7-92			10-8-92			31-8-92		
position*		r	ir	m	r	ir	m	r	ir	m	r	ir	m
layer (cm)	0 - 10	21	18	20	11	16	14	0	0	0	0	0	0
	10 - 20	23	19	21	18	17	17	1	0	1	0	0	0
	20 - 30	16	17	16	21	17	19	4	8	6	0	0	0
	30 - 50	43	40	41	38	41	40	33	26	30	0	0	0
	50 - 70	43	44	44	40	39	39	36	26	31	2	1	1
	70 -100			1			10			7			0
	100 -130			1			0			0			0
	130 -170			1			1			0			0
	0 - 20	44	37	40	29	33	31	1	0	1	0	0	0
	0 - 50	102	94	98	88	92	90	38	34	36	0	1	1
	0 - 70	145	139	142	128	131	129	75	60	67	2	1	2
	0 -170			145			140			74			3

* r=under the maize row, ir=in between the maize row, m=mean of both values (0-70 cm) or random sample (70-170 cm)

Appendix 5.6 Soil mineral N (ceramic cup and RHIZON SSS tube samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 2, placed fertilizer in between the rows)

		date											
		6-7-92			20-7-92			10-8-92			31-8-92		
position*		r	ir	m	r	ir	m	r	ir	m	r	ir	m
layer (cm)	0 - 10	24	45	35	20	87	53	0	3	2	0	0	0
	10 - 20	22	20	21	19	21	20	3	31	17	0	0	0
	20 - 30	27	23	25	24	28	26	17	16	17	0	0	0
	30 - 50	38	35	37	50	56	53	30	39	35	2	7	4
	50 - 70	39	46	43	52	65	59	38	40	39	8	26	17
	70 -100			0			37			22			15
	100 -130			1			1			0			1
	130 -170			1			0			0			1
	0 - 20	46	65	55	38	108	73	3	34	18	0	0	0
	0 - 50	111	123	117	112	192	152	50	90	70	2	7	5
	0 - 70	150	170	160	164	258	211	88	129	109	11	33	22
	0 -170			161			248			132			38

* r=under the maize row, ir=in between the maize row, m=mean of both values (0-70 cm) or random sample (70-170 cm)

Appendix 5.7 Soil mineral N (ceramic cup and RHIZON SSS tube samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 2, broadcast fertilizer)

		date											
		6-7-92			20-7-92			10-8-92			31-8-92		
position*		r	ir	m	r	ir	m	r	ir	m	r	ir	m
layer (cm)	0 - 10	42	41	42	61	43	52	1	1	1	0	0	0
	10 - 20	17	15	16	28	15	22	1	0	1	0	0	0
	20 - 30	16	13	15	25	22	24	12	14	13	0	0	0
	30 - 50	39	34	37	53	52	53	37	31	34	1	2	2
	50 - 70	40	39	40	58	68	63	37	40	38	2	23	12
	70 -100			0			20			12			8
	100 -130			1			1			1			5
	130 -170			1			1			1			1
	0 - 20	60	56	58	89	59	74	2	1	2	0	0	0
	0 - 50	115	104	109	167	132	150	52	45	48	1	2	2
	0 - 70	155	142	149	225	201	213	89	85	87	3	25	14
	0 -170			150			234			100			28

* r=under the maize row, ir=in between the maize row, m=mean of both values (0-70 cm) or random sample (70-170 cm)

Appendix 5.8 Soil mineral N (ceramic cup and RHIZON SSS tube samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 2, placed fertilizer next to the rows)

		date											
		6-7-92			20-7-92			10-8-92			31-8-92		
position*		r	ir	m	r	ir	m	r	ir	m	r	ir	m
layer (cm)	0 - 10	61	16	39	130	21	75	2	0	1	0	0	0
	10 - 20	16	17	16	21	22	22	3	0	2	0	0	0
	20 - 30	17	17	17	21	20	21	16	10	13	0	0	0
	30 - 50	30	31	31	43	47	45	31	29	30	0	1	0
	50 - 70	29	34	32	54	51	53	36	34	35	21	11	16
	70 -100			1			11			8			2
	100 -130			1			1			0			1
	130 -170			1			0			1			1
	0 - 20	77	33	55	151	43	97	5	0	3	0	0	0
	0 - 50	125	81	103	215	110	163	52	39	46	0	1	1
	0 - 70	154	115	135	269	162	215	88	73	81	22	12	17
	0 -170			137			227			89			20

* r=under the maize row, ir=in between the maize row, m=mean of both values (0-70 cm) or random sample (70-170 cm)

Apendix 5.9 Soil mineral N (ceramic cup and RHIZON SSS tube samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 3, control)

		date											
		20-4-93			4-5-93			25-5-93			15-6-93		
position*		r	ir	m	r	ir	m	r	ir	m	r	ir	m
layer (cm)	0 - 10	22	22	22	17	19	18	14	22	18	0	4	2
	10 - 20	22	19	20	19	17	18	18	18	18	0	3	2
	20 - 30	19	19	19	17	16	17	17	17	17	0	0	0
	30 - 50	44	42	43	41	41	41	42	42	42	23	22	22
	50 - 70	33	33	33	32	33	32	33	34	33	23	29	26
	70 -100			0			0			0			0
	100 -130			0			0			0			0
	130 -170			0			0			0			0
	0 - 20	44	41	43	36	36	36	32	40	36	0	7	4
	0 - 50	107	102	105	94	93	94	91	99	95	23	29	26
	0 - 70	140	135	138	126	126	126	124	133	129	46	58	52
	0 -170			138			126			129			52

* r=under the maize row, ir=in between the maize row, m=mean of both values (0-70 cm) or random sample (70-170 cm)

Appendix 5.10 Soil mineral N (ceramic cup and RHIZON SSS tube samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 3, placed fertilizer in between the rows)

		date											
		20-4-93			4-5-93			25-5-93			15-6-93		
position*		r	ir	m	r	ir	m	r	ir	m	r	ir	m
layer (cm)	0 - 10	22	58	40	20	69	44	26	63	45	1	35	18
	10 - 20	19	19	19	16	15	16	17	19	18	2	27	15
	20 - 30	17	17	17	15	15	15	17	16	16	0	22	11
	30 - 50	35	34	34	34	29	31	39	39	39	24	22	23
	50 - 70	42	42	42	36	35	35	43	45	44	31	36	33
	70 -100			0			0			0			0
	100 -130			1			0			0			1
	130 -170			0			0			0			0
	0 - 20	41	77	59	36	84	60	43	82	63	3	62	32
	0 - 50	92	128	110	85	128	107	98	138	119	28	106	67
	0 - 70	134	170	152	121	163	142	142	183	163	59	142	100
	0 -170			153			143			163			101

* r=under the maize row, ir=in between the maize row, m=mean of both values (0-70 cm) or random sample (70-170 cm)

Appendix 5.11 Soil mineral N (ceramic cup and RHIZON SSS tube samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 3, broadcast fertilizer)

		date											
		20-4-93			4-5-93			25-5-93			15-6-93		
position*		r	ir	m	r	ir	m	r	ir	m	r	ir	m
layer (cm)	0 - 10	37	34	36	37	25	31	46	40	43	5	32	18
	10 - 20	25	25	25	17	15	15	20	20	20	5	17	11
	20 - 30	18	18	18	15	16	16	18	18	18	3	5	4
	30 - 50	38	38	38	34	32	33	42	43	42	20	28	24
	50 - 70	39	40	39	32	31	32	46	44	45	36	39	37
	70 -100			0			3			0			0
	100 -130			1			1			0			1
	130 -170			0			0			0			1
	0 - 20	62	60	61	54	40	47	66	60	63	10	48	29
	0 - 50	117	115	116	103	87	95	125	121	123	33	81	57
	0 - 70	156	155	156	135	118	127	171	165	168	69	120	94
	0 -170			157			131			168			96

* r=under the maize row, ir=in between the maize row, m=mean of both values (0-70 cm) or random sample (70-170 cm)

Appendix 5.12 Soil mineral N (ceramic cup and RHIZON SSS tube samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 3, placed fertilizer next to the rows)

		date											
		20-4-93			4-5-93			25-5-93			15-6-93		
position*		r	ir	m	r	ir	m	r	ir	m	r	ir	m
layer (cm)	0 - 10	88	23	55	67	16	41	71	19	45	31	4	18
	10 - 20	22	25	23	17	16	16	20	21	20	19	4	12
	20 - 30	20	20	20	17	17	17	21	21	21	9	11	10
	30 - 50	34	35	35	31	30	31	38	36	37	23	26	25
	50 - 70	42	41	42	37	40	38	45	45	45	31	35	33
	70 -100			0			0			0			0
	100 -130			3			0			0			1
	130 -170			1			0			0			1
	0 - 20	110	48	79	83	32	58	92	40	66	51	8	29
	0 - 50	164	103	134	131	80	105	150	97	124	83	45	64
	0 - 70	206	145	175	168	119	144	196	142	169	114	80	97
	0 -170			179			144			169			99

* r=under the maize row, ir=in between the maize row, m=mean of both values (0-70 cm) or random sample (70-170 cm)

Appendix 5.13 Soil mineral N (ceramic cup and RHIZON SSS tube samplings, kg ha^{-1}) as related to date, depthand lateral position (Experiment 4, control)

position*		5-7-93			19-7-93			10-8-93			30-8-93		
		r	ir	m	r	ir	m	r	ir	m	r	ir	m
layer (cm)	0 - 10	34	26	30	32	27	29	13	21	17	1	1	1
	10 - 20	28	32	30	30	31	31	29	32	30	1	5	3
	20 - 30	24	25	25	26	26	26	25	26	25	4	4	4
	30 - 50	50	50	50	52	52	52	52	52	52	53	51	52
	50 - 70	50	50	50	53	54	54	54	55	55	70	69	69
	70 -100			0			0			0			0
	100 -130			0			0			0			0
	130 -170			0			0			0			0
	0 - 20	58	62	60	61	59	60	42	52	47	1	6	4
	0 - 50	136	133	135	139	136	138	119	131	125	58	61	60
	0 - 70	186	183	184	192	190	191	173	185	179	128	130	129
	0 -170			185			191			180			129

* r=under the maize row, ir=in between the maize row, m=mean of both values (0-70 cm) or random sample (70-170 cm)

Appendix 5.14 Soil mineral N (ceramic cup and RHIZON SSS tube samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 4, placed fertilizer in between the rows)

position*		5-7-93			19-7-93			10-8-93			30-8-93		
		r	ir	m	r	ir	m	r	ir	m	r	ir	m
layer (cm)	0 - 10	44	314	179	47	167	107	31	9	20	3	39	21
	10 - 20	29	27	28	28	32	30	29	39	34	1	57	29
	20 - 30	26	27	26	28	29	28	26	28	27	22	33	28
	30 - 50	48	49	49	52	51	51	51	49	50	51	55	53
	50 - 70	48	51	50	53	53	53	54	52	53	51	49	50
	70 -100			0			0			0			0
	100 -130			0			1			0			0
	130 -170			0			0			0			1
	0 - 20	73	341	207	76	199	138	60	48	54	4	96	50
	0 - 50	147	417	282	155	279	217	136	124	130	77	184	131
	0 - 70	196	468	332	208	333	270	190	176	183	128	234	181
	0 -170			332			271			184			182

* r=under the maize row, ir=in between the maize row, m=mean of both values (0-70 cm) or random sample (70-170 cm)

Appendix 5.15 Soil mineral N (ceramic cup and RHIZON SSS tube samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 4, broadcast fertilizer)

		date											
		5-7-93			19-7-93			10-8-93			30-8-93		
position*		r	ir	m	r	ir	m	r	ir	m	r	ir	m
layer (cm)	0 - 10	64	47	56	79	69	74	63	52	57	6	19	13
	10 - 20	29	27	28	31	29	30	32	28	30	20	4	12
	20 - 30	20	23	22	27	25	26	26	26	26	27	34	31
	30 - 50	52	50	51	54	55	54	56	50	53	64	61	62
	50 - 70	50	53	51	58	59	58	58	30	44	61	62	62
	70 -100			0			0			0			0
	100 -130			0			0			0			0
	130 -170			0			0			0			0
	0 - 20	93	75	84	111	98	104	95	80	88	26	23	25
	0 - 50	165	148	157	191	178	185	176	155	166	117	118	118
	0 - 70	215	201	208	249	237	243	235	185	210	178	180	179
	0 -170			209			243			210			180

* r=under the maize row, ir=in between the maize row, m=mean of both values (0-70 cm) or random sample (70-170 cm)

Appendix 5.16 Soil mineral N (ceramic cup and RHIZON SSS tube samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 4, placed fertilizer next to the rows)

		date											
		5-7-93			19-7-93			10-8-93			30-8-93		
position*		r	ir	m	r	ir	m	r	ir	m	r	ir	m
layer (cm)	0 - 10	80	29	55	89	31	60	44	20	32	7	1	4
	10 - 20	33	27	30	35	29	32	32	30	31	68	7	38
	20 - 30	24	23	24	26	25	26	25	18	21	54	19	37
	30 - 50	59	55	57	61	58	60	57	56	56	62	61	62
	50 - 70	49	50	49	50	52	51	52	52	52	50	48	49
	70 -100			0			0			0			0
	100 -130			0			0			1			0
	130 -170			0			0			0			0
	0 - 20	113	56	85	124	60	92	75	50	63	75	8	41
	0 - 50	196	134	165	211	143	177	156	124	140	191	88	140
	0 - 70	245	184	215	261	195	228	208	176	192	241	136	189
	0 -170			215			228			193			189

* r=under the maize row, ir=in between the maize row, m=mean of both values (0-70 cm) or random sample (70-170 cm)

Appendix 5.17 Soil mineral N (soil core samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 1)

treatment**	layer (cm)	date					
		21-4-92			22-6-92		
		r	ir	m	r	ir	m
C	0 - 10	9	9	9	6	16	11
	10 - 20	7	8	7	3	4	3
	20 - 30	7	8	7	4	3	4
	30 - 50	12	13	13	12	14	13
	50 - 70	14	16	15	14	39	27
	0 - 20	16	17	17	8	20	14
	0 - 50	36	37	36	24	37	31
	0 - 70	49	54	52	38	76	57
IR	0 - 10	9	15	12	13	144	78
	10 - 20	9	8	9	3	49	26
	20 - 30	8	9	8	4	22	13
	30 - 50	14	14	14	16	36	26
	50 - 70	14	14	14	22	21	21
	0 - 20	18	23	21	16	193	104
	0 - 50	39	46	43	36	251	144
	0 - 70	53	60	57	58	272	165
B	0 - 10	49	83	66	56	7	32
	10 - 20	25	34	29	3	6	5
	20 - 30	9	8	9	4	5	4
	30 - 50	13	13	13	13	17	15
	50 - 70	14	24	19	29	20	24
	0 - 20	74	117	96	59	14	36
	0 - 50	97	138	118	76	36	56
	0 - 70	111	163	137	104	56	80
R	0 - 10	11	7	9	5	2	4
	10 - 20	8	8	8	3	2	2
	20 - 30	8	7	8	5	5	5
	30 - 50	13	13	13	21	19	20
	50 - 70	15	14	14	24	21	22
	0 - 20	19	15	17	8	4	6
	0 - 50	40	36	38	34	27	31
	0 - 70	55	50	53	58	48	53

* C=control, IR=placed fertilizer in between the rows, B=broadcast fertilizer, R=placed fertilizer next to the row

** r=under the maize row, ir=in between the maize row, m=mean of both values

Appendix 5.18 Soil mineral N (soil core samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 2)

treatment**	layer (cm)	date					
		6-7-92			31-8-92		
		r	ir	m	r	ir	m
C	0 - 10	20	20	20	26	46	36
	10 - 20	18	19	19	7	12	10
	20 - 30	18	18	18	4	3	4
	30 - 50	35	34	34	6	5	5
	50 - 70	35	35	35	8	8	8
	0 - 20	38	39	38	33	58	46
	0 - 50	91	90	91	43	66	54
	0 - 70	125	125	125	51	74	63
IR	0 - 10	18	23	21	16	198	107
	10 - 20	18	18	18	13	6	10
	20 - 30	18	18	18	5	4	4
	30 - 50	36	36	36	10	12	11
	50 - 70	39	40	40	21	39	30
	0 - 20	36	41	39	29	204	116
	0 - 50	91	95	93	44	220	132
	0 - 70	130	136	133	65	258	162
B	0 - 10	60	77	68	9	175	92
	10 - 20	43	50	46	5	67	36
	20 - 30	20	23	22	6	6	6
	30 - 50	38	38	38	6	7	7
	50 - 70	40	46	43	15	55	35
	0 - 20	103	127	115	14	241	128
	0 - 50	161	188	175	26	254	140
	0 - 70	201	234	218	41	309	175
R	0 - 10	20	22	21	46	21	33
	10 - 20	24	19	21	147	42	95
	20 - 30	20	18	19	21	4	13
	30 - 50	40	39	40	6	7	6
	50 - 70	37	38	37	73	14	44
	0 - 20	44	40	42	193	63	128
	0 - 50	104	97	101	220	74	147
	0 - 70	141	135	138	293	88	191

* C=control, IR=placed fertilizer in between the rows, B=broadcast fertilizer, R=placed fertilizer next to the row

** r=under the maize row, ir=in between the maize row, m=mean of both values

Appendix 5.19 Soil mineral N (soil core samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 3)

treatment**	layer (cm)	date					
		19-4-93			15-6-93		
		r	ir	m	r	ir	m
C	0 - 10	24	19	22	7	25	16
	10 - 20	22	22	22	6	55	30
	20 - 30	22	22	22	6	16	11
	30 - 50	45	40	43	17	18	17
	50 - 70	41	43	42	33	37	35
	0 - 20	46	41	44	13	80	46
	0 - 50	113	103	109	35	113	74
	0 - 70	154	146	151	68	150	109
IR	0 - 10	21	19	20	15	309	162
	10 - 20	21	21	21	4	78	41
	20 - 30	20	20	20	8	11	9
	30 - 50	41	41	41	29	27	28
	50 - 70	41	41	41	43	27	35
	0 - 20	42	40	41	19	386	203
	0 - 50	103	101	102	55	424	239
	0 - 70	144	142	143	98	451	274
B	0 - 10	60	46	53	117	90	103
	10 - 20	34	33	34	10	28	19
	20 - 30	21	22	22	20	14	17
	30 - 50	39	41	40	226	39	132
	50 - 70	41	40	41	39	41	40
	0 - 20	94	79	87	127	117	122
	0 - 50	154	142	149	372	170	271
	0 - 70	195	182	190	410	210	310
R	0 - 10	22	18	20	89	20	54
	10 - 20	26	25	26	37	10	23
	20 - 30	21	21	21	10	13	11
	30 - 50	41	39	40	51	39	45
	50 - 70	42	40	41	39	33	36
	0 - 20	48	43	46	125	29	77
	0 - 50	110	103	107	186	81	133
	0 - 70	152	143	148	225	114	169

* C=control, IR=placed fertilizer in between the rows, B=broadcast fertilizer, R=placed fertilizer next to the row

** r=under the maize row, ir=in between the maize row, m=mean of both values

Appendix 5.20 Soil mineral N (soil core samplings, kg ha^{-1}) as related to date, depth and lateral position (Experiment 4)

treatment**	layer (cm)	date					
		6-7-93			31-8-93		
		r	ir	m	r	ir	m
C	0 - 10	27	31	29	11	6	8
	10 - 20	29	29	29	5	3	4
	20 - 30	29	29	29	6	6	6
	30 - 50	62	61	62	56	59	57
	50 - 70	60	61	61	54	63	58
	0 - 20	56	60	58	15	8	12
	0 - 50	147	150	149	77	73	75
	0 - 70	207	211	210	130	136	133
IR	0 - 10	29	23	26	16	106	61
	10 - 20	29	32	31	5	82	44
	20 - 30	27	30	29	10	90	50
	30 - 50	55	60	58	57	87	72
	50 - 70	58	59	59	49	58	53
	0 - 20	58	55	57	21	188	104
	0 - 50	140	145	143	87	365	226
	0 - 70	198	204	201	136	423	279
B	0 - 10	67	73	70	19	240	129
	10 - 20	58	36	47	14	107	61
	20 - 30	28	27	28	21	23	22
	30 - 50	57	59	58	64	55	59
	50 - 70	59	70	65	66	80	73
	0 - 20	125	109	117	33	347	190
	0 - 50	210	195	203	117	425	271
	0 - 70	269	265	268	183	505	344
R	0 - 10	28	31	30	41	34	37
	10 - 20	28	28	28	27	6	16
	20 - 30	28	29	29	23	20	22
	30 - 50	61	55	58	74	64	69
	50 - 70	57	56	57	63	61	62
	0 - 20	56	59	58	67	40	53
	0 - 50	145	143	145	164	124	144
	0 - 70	202	199	201	227	185	206

* C=control, IR=placed fertilizer in between the rows, B=broadcast fertilizer, R=placed fertilizer next to the row

** r=under the maize row, ir=in between the maize row, m=mean of both values

Appendix 6:
^{15}N atom %

Appendix 6. ^{15}N atom % of maize at harvest

experiment number	treatment*	^{15}N atom %			
		roots	stem	leaves	shoot
1	C	0.328	0.411	0.400	0.406
	IR	0.296	0.273	0.295	0.284
	B	0.299	0.300	0.304	0.302
	R	0.214	0.261	0.243	0.253
2	C	0.385	0.396	0.388	0.393
	IR	0.315	0.319	0.284	0.307
	B	0.314	0.339	0.306	0.327
	R	0.301	0.324	0.276	0.308
3	C	0.341	0.350	0.350	0.350
	IR	0.319	0.319	0.329	0.323
	B	0.272	0.290	0.284	0.287
	R	0.221	0.279	0.245	0.263
4	C	0.340	0.342	0.338	0.340
	IR	0.294	0.289	0.299	0.294
	B	0.265	0.286	0.281	0.284
	R	0.219	0.273	0.257	0.265

* C=control, IR=placed fertilizer in between the rows, B=broadcast fertilizer, R=placed fertilizer next to the row