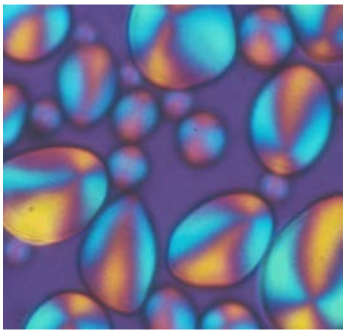
International
Starch
Institute

POTATO JUICE AS A FERTILIZER TM3-5e



Starch Technology

Introduction[1]

Potato and tapioca starch is produced from fresh raw materials with a high content of juice. The extraction of starch also releases the juice. The juice is recycled to the fields and this technical memorandum describes the effect of utilizing the juice from potatoes as a fertilizer.

The Danish starch industry processes more than half of the domestic potato crop. Production of potato starch has multiplied during the membership of the EEC, and so has the outlet of potato juice. Accordingly, the utilization of the valuable nutrients in potato juice is of great concern.

Potatoes contain approx. 70% of juice with approximately 5% of dry matter - half of which is sugars and protein bringing about 30,000 ppm BOD_5 in the concentrated juice. Being a natural product variation occur. The juice also contains potassium and magnesium and a typical analysis of fruit juice is:

Vacuum probe.

Constituents of the potato juice:		
Nitrogen, N	4,300 ppm	equivalent to 26,875 ppm protein
Phosphorus, P	490 ppm	
Potassium, K	4,900 ppm	
Magnesium, Mg	260 ppm	
Dry substance	5.1 %	

These nutrients are all valuable fertilizers. Exactly how valuable and exactly what will happen when used according to good agricultural practice, were the questions to be answered by a 3- year study starting September 1988 and ending September 1991. In this study potato fruit juice was applied on grass and black uncropped soil in the autumn and spring in different quantities.

Summary and Conclusion.

The effect of manuring with potato juice on sandy soil has been studied during a three-year test period.

All three winters were mild and with a considerable nitrogen mineralization throughout the winter. The adverse effect is to some degree compensated for by the better growing conditions of grass, which has proved quite efficient in absorbing the minerals released.

Update 2014.

Today approximately half the juice protein is heat precipitated and the residual juice is evaporated to 33-40 % DM - a kind of syrup sold and used as an organic fertilizer named Protamylasse.

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[1] The agricultural test has been planned, supervised and results interpreted by Svend Erik Simmelsgaard, The Danish Institute of Plant and Soil Science, Department of Soil Physics, Soil Tillage and Irrigation in cooperation with Lars Thomsen, International Starch Institute A/S.

Table 11. Leaching of ammonium-nitrogen 1. September - 31. August. 1988-91. kg/ha per year. KFS = Potato Juice; HG = Artificial Fertilizer Compound								
N-applied	Rye grass as catch-crop				Uncropped during winter			
Time:	KFS SEP	KFS NOV	KFS MAR	HG MAR	KFS NOV	KFS+ NOV	KFS MAR	HG MAR
Basic dressing	0.13	0.13	0.13	0.13	-	-	-	-
+ 50 N	0.13	0.24	0.13	0.09	-	-	-	0.24
+100 N	0.20	0.21	0.37	0.12	1.14	1.84	0.15	0.15
+150 N	-	0.28	0.11	-	-	-	-	-
LSD (95%)	0.20				1.08			

Potato juice equivalent to 100 kg nitrogen per ha applied in the autumn to black (uncropped) fields gave high losses of nitrogen during the winter due to nitrogen leaching.

Use of potato juice equivalent to 100 kg nitrogen per ha on grass as a catch crop in the autumn does not give any significant leaching of nitrogen during the winter. The utilization of nitrogen the following growing season is therefore as high as 70-80%. Potato juice equivalent to 150 kg N/ha in November increases leaching significantly and the utilization decreases correspondingly.

Table 15. Leaching of potassium 1. September - 31. August. 1988-91. kg/ha per year.								
N-applied	Rye grass as catch-crop				Uncropped during winter			
Time:	KFS SEP	KFS NOV	KFS MAR	HG MAR	KFS NOV	KFS+ NOV	KFS MAR	HG MAR
Basic dressing	35	35	35	35	-	-	-	-
+ 50 N	37	34	31	32	-	-	-	41
+100 N	40	42	32	31	64	62	39	39
+150 N	-	48	31	-	-	-	-	-
LSD (95%)	5				11			

Leaching of potassium does not completely match the pattern found for nitrogen.

By application in spring just prior to sowing, utilization of nitrogen in potato juice of 80-85% is expected.

Calibration of juice spreader. The distribution of juice is checked before and after application on each plot

A mini harvester in use. The crop on individual plots are collected and measured.

Harvest of test plots. Yield of grain and straw are monitored on each plot.

Vacuum probes with thin plastic tubes connected through the top stopper. The leaching of nutrients is monitored for each plot every week over a three-year period.

Method

The experiment was divided in 16 treatments, each with 4 repetitions as follows:

A. GREEN Catch crop: Rye grass					B. BLACK (Catch crop: None) Round-Up used to remove vegetation.				
1.	Basic manuring				1.	100	N	KFS,	NOV.
2.	50	N	KFS,	SEP	2.	100	N	KFS+inhibitor,	NOV
3.	100	N	KFS,	SEP	3.	50	N	HG,	spring
4.	50	N	KFS,	NOV	4.	100	N	HG,	spring
5.	100	N	KFS,	NOV	5.	100	N	KFS,	spring
6.	150	N	KFS,	NOV					
7.	50	N	HG,	spring					
8.	100	N	HG,	spring					
9.	50	N	KFS,	spring					
10.	100	N	KFS,	spring					
11.	150	N	KFS,	spring					

Basic = Basic dressing with P, K + N (30 kg/ha N) H in spring
HG = Artificial fertilizer
N = Total nitrogen, kg/ha
KFS = Potato juice undiluted
Inhibitor= Nitrification inhibitor

The experiment took place on sandy soil in Jutland, Denmark. All 64 plots had spring barley in all three years. The straw is removed after harvest and the outgrown plots are harvested in the autumn. 20 plots planned without vegetation throughout the winter are then sprayed down with Round-Up. In spring all plots are ploughed. In summer time the plots are irrigated when needed.

For each plot the yields of dry matter, nitrogen and potassium content in grain, straw and stubble are measured. Dry matter and nitrogen content of grass is determined by sampling after harvest, in November and again before ploughing in spring.

The leaching of nitrogen and potassium is calculated on the basis of analysis of soil water taken out at a depth of 80 cm, combined with model calculations of the percolation in the same depth.

The soil water is sampled by vacuum. A hole is drilled down below the root zone. A vacuum probe is forced down the hole to the bottom and sealed carefully with volcanic clay. In most cases the seal was efficient to keep vacuum for more than a week. The vacuum probe is a plastic pipe with a ceramic cup (filter) at the lower end and a rubber stopper at the top. The stopper is provided with two holes for two thin sampling tubes - a short one to the top of the probe and a longer one to the bottom of the probe. With a portable vacuum pump connected to the short tube the probe is put under vacuum and the tube is closed. The vacuum slowly draws soil water into the probe. During sampling air pressure is applied to the short tube forcing trapped water up and out through the long tube into a bottle. Because the ceramic filter is below the root zone the sampled water represents a potential leaching hazard. Each test plot is provided with two sampling tubes. That means a total of 8 samplings per treatment and a total of 128 samples each day of sampling. The two samples from each plot are mixed to a joint sample for that plot. On average, sampling is done every second week. Each soil water sample is analyzed for nitrate. Potassium and ammonium is analyzed monthly.

The soil water analysis is supplemented with analysis of soil samples taken 0-25, 25-50 and 50-75 cm below soil surface before the out-bringing of juice in September, November and March. 4 - 5 samples are taken from each plot and mixed, which means 17 - 20 samples per treatment. Before starting the trial, soil samples have been analyzed for pH, potassium (K), phosphor (P) and total nitrogen (N), total organic carbon C and texture. In the experiment period each soil sample is analyzed for nitrate + ammonium (N_{min}) and potassium. At the end of the test total nitrogen and total organic carbon have been measured.

Before the start of the test four soil profiles have been described. In each profile 18 cores of undisturbed soil (volume = 100 cm^3) - five from a depth of 10 and 37 cm, four samples from a depth of 52 and 77 cm - were sampled for retention analysis. From the retention analysis the root zone capacity for plant available water were calculated.

The calculations of actual evaporation/transpiration and percolation are performed on the basis of climate data obtained from a nearby weather station. Only rainfall is measured directly on the test area. For the calculations the Evacrop[2] water balance model is used. The leaching is calculated by multiplying the percolation with the average concentration between two sampling dates.

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[2] Reference: *AjMet nr. 9, Department of Agricultural Meteorology, Institute of Plant and Soil Science*

The soil is coarse sandy and classified as JB no 1 in the Danish classification system. The analysis of texture is shown in table 1. There is a tendency towards forming of hard pan in part of the area, which has been grubbed (broken) earlier. The underground is somewhere graveled.

Climate

The average temperature and rainfall are shown in figure 2.

Table 5 gives the water balance for the 3 years of test calculated from 1st of September to the 31st of August and figure 5 shows the calculated amounts of percolation.

In figure 1 the retention curve is shown. The retention curves show the relation between the logarithms and the suction in cm (pF) and the water content of the soil gives thereby an impression of the ability to retain water.

In table 2 dry volume weight, porosity and the water capacity calculated from the retention curves are shown. The volume weight and the porosity are normal for the soil type.

With an estimated efficient depth of the plant roots of 60 cm the root zone capacity for plant available water is 72 cm. In the area with hard pan the efficient depth of the plant roots is estimated to be less than 60 cm. There is compensation - the soil in this area will be expected to retain a little more water at field capacity, which will compensate for a minor depth of the roots.

In table 3 the results of chemical analysis of soil samples taken at the start of the September 1988 are shown. pH and phosphor content P is normal, while potassium K and magnesium Mg are low. The carbon content of the soil in relation to organic bound nitrogen, C/N, is rather high, which means that a tendency towards immobilization of nitrogen is to be expected.

The out-bringing of potato juice (PJ).

A Hardi field sprayer is used for the out-bringing of the potato juice. The pump yields 150 to 160 liters per minute with a pressure of 2.5 bar. On a 5 m long spraying boom 19 nozzles are mounted. Before and after each application of potato juice the yield of the spray equipment was monitored.

The speed of the tractor was adjusted so each passing of a plot gave exactly 50 kg of nitrogen per ha. The speed was stopwatch-monitored and the amount of potato juice was also monitored by collecting fruit juice in four trays placed on each plot during passing. The figures obtained are shown in table 4. The stopwatch method is well in agreement with the method of collecting juice in trays, except for one treatment in November 1989 where heavy wind drift may have compromised the sampling. The out-bringing has been based on estimated values for nitrogen content, which in 1989 gave some disagreement between the two methods.

Plots not fertilized with fruit juice and plots fertilized with only 50 and 100 kg of nitrogen per ha as fruit juice had received supplementary potassium and phosphor as PK-fertilizer. Nitrogen was given in the form of calcium-ammonium-nitrate (KAS).

The actual quantities of nitrogen and potassium per plot are given in table A5 to A12.

Protamylasse.

Figure 1. Protamylasse applied as a fertilizer by land spreading.

Protamylasse ingredients:

Density:	1,2 ton per m^3
Dry matter:	33 %
Nitrogen, N:	18-20 kg per ton
Phosphorous, P:	3-4 kg per ton
Potassium, K:	45-50 kg per ton
Magnesium, Mg:	2-4 kg per ton
Sulfur, S:	5-7 kg per ton

Abbreviations

KFS	Potato juice undiluted
KFS+	Potato juice with nitrification inhibitor (Didin) added
HG	Artificial fertilizer
KAS	Calcium Ammonium Nitrate (Kalkammonsalpeter)
N	Nitrogen
K	Potassium
P	Phosphorous
C	Carbon
LSD	Least significant difference
SEP	September
NOV	November
MAR	Marts

N-balance=N_{til} - N_{opt} + N_{min}(start) - N_{min}(end)

N_{til}	Nitrogen added as KFS or HG. Nitrogen from other sources (app. 20 N kg/ha) rainfall, irrigation etc. is not included in balance calculations
N_{opt}	Nitrogen retained in grain and stubble
N_{udv}	Nitrogen washed out
N_{min}	Nitrogen inorganic (mineralized)
UDL	Barley with undersown rye grass

Table 1. Texture analysis, per cent of dry soil						
Depth cm	Humus Org. matter	Clay <0.002	Silt <0.02	Fine sand <0.2	Coarse sand <2 mm	Gravel/ stone >2 mm
0-25	3.2	3.9	3.1	23.2	62.7	4.0
25-50	1.4	3.2	1.7	22.2	64.8	6.8
50-75	0.5	2.6	0.9	20.3	68.5	7.3

Table 2. Soil volume weight, porosity and water capacity					
Depth cm	Volume-weight g/cm^3	Porosity %	Field capacity pF = 2.0 mm	Plant in-available water pF = 4.2 mm	Plant available water mm
0-25	1.47	43.4	48.2	11.0	37.2
25-45	1.53	41.9	26.2	5.3	20.9
45-60	1.48	43.9	16.2	2.6	13.6
60-100	1.56	41.1	47.6	4.4	43.2
0-60	-	-	91	19	72*
0-100	-	-	138	23	115
* Root zone capacity					

Table 3. Chemical soil analysis.							
Depth cm	pH water	P	K	Mg	Total-C %	Total N %	C/N
		mg/100g soil					
0-25	6.5	4.3	4.3	1.7	1.90	0.092	20.7
25-50	5.9	1.1	2.4	0.7	0.89	0.035	25.5
50-75	5.9	0.2	1.4	0.3	0.31	0.013	24.8
		kg/ha			ton/ha		
0-25	-	158	158	62	69.8	3.38	-
25-50	-	42	92	27	34.0	1.34	-
50-75	-	8	53	11	11.8	0.49	-
0- 75	-	208	303	100	115.6	5.21	22.2

Table 4. Quantity of potato juice applied in one-pass						
Date	Measured		N-content kg/ton	N-applied kg/ha	K-content kg/ton	K-applied kg/ha
	in trays ton/ha	stopwatch ton/ha				
20.09.1988	13.1	13.1	3.9	51	5.1	67
16.11.1988	13.5	13.4	3.6	48	4.6	62
14.03.1989	14.5	14.2	3.4	48	3.9	55
13.09.1989	13.7	13.9	5.3	73	5.4	75
15.11.1989	11.8	14.0	4.7	66	4.9	69
21.03.1990	14.8	14.7	3.4	50	4.4	65
24.09.1990	14.5	13.7	3.7	51	3.6	49
15.11.1990	12.1	11.7	4.3	50	5.0	59
20.03.1991	11.0	11.8	3.8	44	4.3	50

Table 5. Rainfall, irrigation, evaporation and run off 1. SEP - 31. Aug., 1988-91, mm per year.						
Year	Rainfall	Irrigation	Evaporation		Run off	
	Precipi.		Barley	UDL	Barley	UDL
1988/89	797	68	449	466	455	451
1989/90	851	76	455	497	451	420
1990/91	882	17	388	409	541	506

UDL = Barley with undersown grass.

Table 6. Grain yield of spring barley (85% DS), hkg/ha.								
N-applied	Rye grass catch-crop.				Uncropped during winter			
Time:	KFS SEP	KFS NOV	KFS MAR	HG MAR	KFS NOV	KFS+ NOV	KFS MAR	HG MAR
1989:								
Basic dressing	27.0	27.0	27.0	27.0	-	-	-	-
+ 50 N	35.7	38.0	33.6	33.0	-	-	-	30.4
+100 N	43.3	44.7	41.6	41.6	24.0	25.2	38.4	37.5
+150 N	-	47.3	45.8	-	-	-	-	-
LSD (95%)	3.8				2.4			
1990:								
Basic dressing	34.7	34.7	34.7	34.7	-	-	-	-
+ 50 N	40.5*	43.8*	43.9	48.2	-	-	-	47.5
+100 N	46.9*	49.3*	53.7	58.6	33.1	34.7	51.0	55.2
+150 N	-	51.0*	61.2	-	-	-	-	-
LSD (95%)	2.7				2.2			
1991:								
Basic dressing	23.8	23.8	23.8	23.8	-	-	-	-
+ 50 N	30.6	30.8	29.5	32.7	-	-	-	22.0
+100 N	33.9	34.4	34.8	38.9	15.1	16.4	23.9	25.9
+150 N	-	35.1	39.4	-	-	-	-	-
LSD (95%)	2.7				2.3			
Average 1989-91:								
Basic dressing	28.5	28.5	28.5	28.5	-	-	-	-
+ 50 N	36.5	38.5	35.6	37.9	-	-	-	33.3
+100 N	43.2	43.1	43.4	46.3	24.1	25.4	37.7	39.5
+150 N	-	44.5	48.8	-	-	-	-	-
LSD (95%)	2.6				1.1			

*Corrected to yield by nominal N-applied
KFS = Potato juice, KFS+ = Potato juice + nitrification inhibitor, HG = Artificial fertilizer.

Table 7. Content of nitrogen in rye grass (top + stubble), kg/ha

Treatment	1988/89	1989/90			1990/91		
	MAR	Har-vest	NOV	MAR	Har-vest	NOV	MAR
1. Basic dressing	44	6	23	19	5	16	22
2. 50 N i KFS, SEP	67	-	57	45	5	28	41
3. 100 N i KFS, SEP	103	-	91	66	5	36	60
4. 50 N i KFS, NOV	63	-	26	34	5	22	40
5. 100 N i KFS NOV	76	-	23	33	4	19	46
6. 150 N i KFS NOV	91	-	27	34	4	22	45
8. 100 N i HG, MAR	-	-	-	22	-	16	27
9. 50 N i KFS, MAR	-	6	-	-	-	-	
10 100 N i KFS, MAR	-	6	-	21	7	23	28
11 150 N i KFS, MAR	-	7	36	-	-	-	

Table 8. Nitrogen content in grain + straw.
Average 1989-91, kg/ha.

N-applied	Rye grass catch-crop				Uncropped during winter			
	KFS	KFS	KFS	HG	KFS	KFS+	KFS	HG
Time:	SEP	NOV	MAR	MAR	SEP	NOV	MAR	MAR
Basic dressing	38.7	38.7	38.7	38.7	-	-	-	-
+ 50 N	52.8	55.4	51.3	54.0	-	-	-	49.2
+100 N	68.2	64.9	69.8	73.4	36.1	37.9	60.7	65.3
+150 N	-	71.4	89.4	-	-	-	-	-
LSD (95%)	******* 3.9 ********				******** 2.0 *******			

Table 9.Potassium content in grain + straw.
Average 1989-91, kg/ha.

N-applied	Rye grass catch-crop				Uncropped during winter			
	KFS	KFS	KFS	HG	KFS	KFS+	KFS	HG
Time:	SEP	NOV	MAR	MAR	SEP	NOV	MAR	MAR
Basic dressing	28.0	28.0	28.0	28.0	-	-	-	-
+ 50 N	38.4	40.7	45.5	39.9	-	-	-	40.5
+100 N	49.3	46.7	50.9	52.3	30.1	31.3	51.2	49.4
+150 N	-	48.5	64.1	-	-	-	-	-
LSD (95%)	******** 5.8 ********				******** 2.8 *******			

Table 10. Leaching of nitrate nitrogen
1. September - 31. August. kg/ha.

N-applied	Rye grass catch-crop				Uncropped fields			
	KFS	KFS	KFS	HG	KFS	KFS+	KFS	HG
Time:	SEP	NOV	MAR	MAR	NOV	NOV	MAR	MAR
1989:								
Basic dressing	5,7	5.7	5.7	5.7	-	-	-	-
+ 50 N	6.7	7.5	4.5	4.7	-	-	-	30.9
+100 N	6.0	8.8	4.1	4.4	98.6	57.0	30.8	30.9
+150 N	-	17.5	6.0	-	-	-	-	-
LSD (95%)	****** 5.4 ********				******* 16.7 *******			
1990:								
Basic dressing	1.7	1.7	1.7	1.7	-	-	-	-
+ 50 N	2.2*	1.5*	1.5	1.5	-	-	-	29.9
+100 N	5.1*	9.2*	3.4	2.9	84.5	63.6	40.1	36.4
+150 N	-	25.3*	1.7	-	-	-	-	-
LSD (95%)	******* 8.7 ********				******** 11.4 ******			
1991:								
Basic dressing	4.8	4.8	4.8	4.8	-	-	-	-
+ 50 N	7.4	15.3	5.0	7.4	-	-	-	59.9
+100 N	15.9	12.6	8.3	10.7	90.4	91.4	68.0	57.6
+150 N	-	33.9	9.9	-	-	-	-	-
LSD (95%)	******* 9.6 ********				******** 10.3 ******			
Ave. 1989-91:								
Basic dressing	4.1	4.1	4.1	4.1	-	-	-	-
+ 50 N	5.4	8.1	3.7	4.5	-	-	-	40.2
+100 N	9.0	10.2	5.3	6.0	91.2	70.7	46.3	41.6
+150 N	-	25.6	5.9	-	-	-	-	-
LSD (95%)	******* 5.1 ********				******** 7.5 *******			

*Corrected to yield at nominal N-applied
KFS+ = Potato juice with nitrification inhibitor added.

Table 11. Leaching of ammonium-nitrogen
1. September - 31. August. 1988-91. kg/ha per year.

N-applied Time:	Rye grass catch-crop				Uncropped during winter			
	KFS SEP	KFS NOV	KFS MAR	HG MAR	KFS NOV	KFS+ NOV	KFS MAR	HG MAR
Basic dressing	0.13	0.13	0.13	0.13	-	-	-	-
+ 50 N	0.13	0.24	0.13	0.09	-	-	-	0.24
+100 N	0.20	0.21	0.37	0.12	1.14	1.84	0.15	0.15
+150 N	-	0.28	0.11	-	-	-	-	-
LSD (95%)	0.20				1.08			

Table 12. Mean concentration of ammonium-nitrogen
weighted in relation to the run off. 1988-91, mg/l.

N-applied Time:	Rye grass catch-crop				Uncropped during winter			
	KFS SEP	KFS NOV	KFS MAR	HG MAR	KFS NOV	KFS+ NOV	KFS MAR	HG MAR
Basic dressing	0.03	0.03	0.03	0.03	-	-	-	-
+ 50 N	0.03	0.05	0.03	0.02	-	-	-	0.05
+100 N	0.04	0.05	0.08	0.03	0.25	0.39	0.03	0.03
+150 N	-	0.06	0.02	-	-	-	-	-

Table 13. Accumulated nitrogen balance, SEP 88 - SEP 91, kg/ha

N-applied	Rye grass catch-crop				Uncropped fields			
	KFS	KFS	KFS	HG	KFS	KFS+	KFS	HG
Time	SEP	NOV	MAR	MAR	NOV	NOV	MAR	MAR
Basic dressing	-53	-53	-53	-53	-	-	-	-
+50 N	70	36	49	49	-	-	-	-49
+100 N	174	155	125	122	30	97	25	41
+150 N	-	234	194	-	-	-	-	-

Table 14. Soil content of total-N at 0 - 25 cm depth
At the end of the trial, SEP 1991, ton/ha.

N-applied	Rye grass catch-crop				Uncropped fields			
	KFS	KFS	KFS	HG	KFS	KFS+	KFS	HG
Time	SEP	NOV	MAR	MAR	NOV	NOV	MAR	MAR
Basic dressing	3.3	3.3	3.3	3.3	-	-	-	-
+50 N	3.5	3.4	3.6	3.7	-	-	-	3.6
+100 N	3.8	3.5	3.6	3.7	3.2	3.3	3.5	3.3
+150 N	-	3.6	3.5	-	-	-	-	-
LSD (95%)	****** 0.4 *******				******* n.s. ******			

Table 15. Leaching of potassium 1. September - 31. August. 1988-91. kg/ha per year.								
N-applied Time:	Rye grass catch-crop				Uncropped during winter			
	KFS SEP	KFS NOV	KFS MAR	HG MAR	KFS NOV	KFS+ NOV	KFS MAR	HG MAR
Basic dressing	35	35	35	35	-	-	-	-
+ 50 N	37	34	31	32	-	-	-	41
+100 N	40	42	32	31	64	62	39	39
+150 N	-	48	31	-	-	-	-	-
LSD (95%)	5				11			

Table 16. Mean concentration of potassium,
weighted in relation to run off, 1988-91, mg/l.

N-applied	Rye grass catch-crop				Uncropped during winter			
	KFS	KFS	KFS	HG	KFS	KFS+	KFS	HG
Time:	SEP	NOV	MAR	MAR	NOV	NOV	MAR	MAR
Basic dressing	7.9	7.9	7.9	7.9	-	-	-	-
+ 50 N	8.5	7.6	7.0	7.2	-	-	-	9.0
+100 N	8.9	9.6	7.4	7.1	13.7	13.2	8.6	8.6
+150 N	-	10.8	7.0	-	-	-	-	-

Table A1. Grain- and straw yield (85% DS.), hkg/ha.

Treatment	Grain 1989	1990	1991	Ave.	Straw 1989	1990	1991	Ave.
A: Catch-crop of rye grass								
1: Basic dress	27.0	34.7	23.8	28.5	12.3	17.6	10.7	13.5
2: 50 N SEP	35.7	43.1	30.6	36.5	16.5	25.7	16.4	19.5
3: 100 N SEP	43.3	52.5	33.9	43.2	21.4	33.9	19.1	24.8
4: 50 N NOV	38.0	46.7	30.8	38.5	17.8	28.7	14.9	20.4
5: 100 N NOV	44.7	50.3	34.4	43.1	21.8	32.1	19.0	24.3
6: 150 N NOV	47.3	51.0	35.1	44.5	24.2	32.3	20.2	25.6
7: 50 N KAS	33.0	48.2	32.7	37.9	16.5	29.5	14.6	20.2
8: 100 N KAS	41.6	58.6	38.9	46.3	20.4	37.1	21.2	26.2
9: 50 N MAR	33.6	43.9	29.5	35.6	16.4	26.6	14.9	19.3
10 100 N MAR	41.6	53.7	34.8	43.4	21.5	34.5	18.3	24.8
11 150 N MAR	45.8	61.2	39.4	48.8	24.8	41.0	25.7	30.5
LSD (95%)	3.8	2.7	2.7	2.6	2.9	3.5	2.7	2.5
B: Uncropped during winter								
1: 100 N NOV	24.0	33.1	15.1	24.1	12.8	21.2	9.9	14.6
2: 100 N NOV+	25.2	34.7	16.4	25.4	11.7	19.9	9.9	14.0
3: 50 N KAS	30.4	47.5	22.0	33.3	15.5	30.0	14.7	20.1
4: 100 N KAS	37.5	55.2	25.9	39.5	20.2	36.7	16.8	24.6
5: 100 N MAR	38.4	51.0	23.9	37.7	19.9	34.0	18.9	24.3
LSD (95%)	2.4	2.2	2.3	1.1	1.5	2.5	2.9	1.6

KAS = calcium ammonium nitrate

Table A2. Nitrogen content in grain and straw, kg/ha.

Treatment	Grain 1989	1990	1991	Ave.	Straw 1989	1990	1991	Ave.
A: Catch-crop of rye grass								
1: Basic dress	30.4	40.4	28.0	32.9	4.9	7.6	4.8	5.8
2: 50 N SEP	40.7	52.9	39.5	44.4	6.6	11.4	7.2	8.4
3: 100 N SEP	52.0	70.1	47.7	56.6	8.7	17.0	9.0	11.6
4: 50 N NOV	43.4	58.1	38.9	46.8	6.9	12.1	6.9	8.6
5: 100 N NOV	54.0	62.6	46.4	54.3	9.5	13.8	8.4	10.6
6: 150 N NOV	61.8	66.2	50.2	59.4	12.1	14.6	9.4	12.0
7: 50 N KAS	37.1	57.7	41.1	45.3	6.6	13.2	6.2	8.7
8: 100 N KAS	48.6	78.9	55.4	61.0	9.3	17.9	10.1	12.4
9: 50 N MAR	37.9	53.0	37.3	42.7	6.7	12.2	6.8	8.6
10 100 N MAR	50.1	72.1	48.6	57.0	11.2	17.9	9.3	12.8
11 150 N MAR	61.4	92.1	62.5	72.0	14.3	23.7	14.1	17.4
LSD (95%)	4.0	3.9	3.8	3.2	1.4	2.2	1.5	1.2
B: Uncropped during winter								
1: 100 N NOV	29.0	39.5	18.4	29.0	5.5	9.5	6.5	7.2
2: 100 N NOV+	30.4	41.3	20.8	30.9	5.5	8.7	6.6	7.0
3: 50 N KAS	35.5	56.4	27.8	39.9	5.9	12.9	9.1	9.3
4: 100 N KAS	45.9	76.6	37.4	53.3	8.0	17.5	10.3	12.0
5: 100 N MAR	46.8	66.2	32.6	48.5	7.9	16.3	12.3	12.2
LSD (95%)	3.4	3.9	3.2	1.7	1.0	1.4	2.3	0.9

Table A3. Potassium content in grain and straw, kg/ha.

Treatment	Grain				Straw			
	1989	1990	1991	Ave.	1989	1990	1991	Ave.
A: Catch-crop of rye grass								
1: Basic dress	10.1	17.3	10.6	12.7	8.0	29.5	8.4	15.3
2: 50 N SEP	13.2	21.4	13.1	15.9	10.6	45.2	11.6	22.5
3: 100 N SEP	15.7	25.8	13.9	18.4	14.4	62.4	15.7	30.8
4: 50 N NOV	13.9	22.9	13.2	16.7	11.2	48.7	12.1	24.0
5: 100 N NOV	16.4	25.3	14.3	18.7	15.5	53.8	14.9	28.0
6: 150 N NOV	17.6	25.1	15.6	19.4	18.9	50.3	18.1	29.1
7: 50 N KAS	12.1	22.9	14.1	16.4	9.5	51.1	10.0	23.5
8: 100 N KAS	14.3	28.6	16.2	19.7	11.7	72.2	14.0	32.6
9: 50 N MAR	12.3	21.6	13.2	15.7	9.8	46.7	32.8	29.8
10: 100 N MAR	15.0	26.5	15.1	18.9	15.8	65.3	15.0	32.1
11: 150 N MAR	16.7	29.9	17.3	21.3	20.4	84.3	23.6	42.8
LSD (95%)	1.5	1.9	2.1	1.4	2.7	7.2	18.7	5.9
B: Uncropped during winter								
1: 100 N NOV	9.4	16.3	6.8	10.8	9.6	33.3	15.1	19.3
2: 100 N NOV+	9.6	16.8	7.4	11.3	9.0	32.6	14.2	19.5
3: 50 N KAS	11.0	22.4	9.6	14.3	9.7	48.2	20.5	26.1
4: 100 N KAS	13.2	26.5	11.2	17.0	12.4	66.2	18.6	32.4
5: 100 N MAR	13.9	24.8	11.0	16.6	13.9	60.3	29.7	34.6
LSD (95%)	0.8	1.1	1.1	0.5	1.8	4.0	6.1	2.4

Table A4. Stubble Yield and N-content in stubble. hkg/ha & kg/ha.

Treatment	Yield				N-content			
	1989	1990	1991	Ave.	1989	1990	1991	Ave.
A: Catch-crop of rye grass								
1: Basic dress.	4.6	10.0	6.0	6.9	2.1	7.3	3.6	4.4
2: 50 N SEP	.	10.0	5.9	7.9	.	7.7	3.8	5.7
3: 100 N SEP	6.2	11.0	6.1	7.8	3.2	8.5	4.0	5.2
4: 50 N NOV	5.7	12.7	5.7	8.0	2.8	9.4	3.7	5.3
5: 100 N NOV	5.9	12.7	6.4	8.3	2.9	10.2	4.1	5.7
6: 150 N NOV	7.1	12.5	6.2	8.6	4.1	10.2	4.2	6.2
7: 50 N KAS	5.5	12.6	6.9	8.4	2.6	10.3	4.5	5.8
8: 100 N KAS	7.2	13.2	7.7	9.4	3.8	11.2	5.8	6.9
9: 50 N MAR	5.6	11.0	5.6	7.4	2.5	9.2	3.6	5.1
10 100 N MAR	5.2	14.7	4.9	8.3	2.7	12.3	3.4	6.1
11 150 N MAR	7.5	11.3	6.5	8.4	4.8	11.3	5.0	7.0
LSD (95%)	-	-	1.8	1.2	-	-	1.2	1.1
B: Uncropped during winter								
1: 100 N NOV	5.0	9.7	4.9	6.5	2.5	8.7	3.3	4.9
2: 100 N NOV+	.	9.2	4.5	6.9	.	7.3	2.8	5.0
3: 50 N KAS	.	14.8	6.8	10.8	.	11.4	4.8	8.1
4: 100 N KAS	6.9	13.2	7.2	9.1	3.9	10.9	5.2	6.7
5: 100 N MAR	7.1	12.8	6.2	8.7	4.2	11.4	4.3	6.6
LSD (95%)	-	-	1.3	1.5	-	-	1.0	1.4

Table A5. Nitrogen balance, SEP 1988 - SEP 1989, kg/ha

Treatment	N added	N retained	N leached	N_{min} 88	N_{min} 89	Balance
Catch-crop of rye grass:						
1A: Basic dress	30	-35	-6	10	-13	-14
2A: 50 N SEP	79	-47	-7	10	-14	22
3A: 100 N SEP	128	-61	-6	10	-22	50
4A: 50 N NOV	79	-50	-8	10	-17	14
5A: 100 N NOV	127	-64	-9	10	-23	42
6A: 150 N NOV	176	-74	-18	10	-28	67
7A: 50 N KAS	80	-44	-5	10	-13	28
8A: 100 N KAS	130	-58	-4	10	-14	64
9A: 50 N MAR	78	-45	-5	10	-15	24
10A 100 N MAR	127	-61	-4	10	-18	53
11A 150 N MAR	175	-76	-6	10	-27	76
LSD (95 %)		4.6	5.4		7.9	
Uncropped during winter:						
1B: 100 N NOV	137	-35	-99	10	-24	-10
2B: 100 N NOV+	133	-35	-57	10	-22	29
3B: 50 N KAS	80	-41	-31	10	-23	-5
4B: 100 N KAS	130	-54	-31	10	-24	31
5B: 100 N MAR	127	-55	-31	10	-29	22
LSD (95 %)		3.7	16.7		9.6	

Table A6. Nitrogen balance, SEP 1989 - SEP 1990, kg/ha

Treatment	N added	N retained	N leached	N_{min} 89	N_{min} 90	Balance
-						
Catch-crop of rye grass:						
1A: Basic dress	30	-48	-2	13	-15	-21
2A: 50 N SEP	103	-64	-3	14	-19	30
3A: 100 N SEP	176	-87	-10	22	-24	77
4A: 50 N NOV	96	-70	-4	17	-24	15
5A: 100 N NOV	162	-77	-18	23	-21	70
6A: 150 N NOV	227	-81	-48	28	-24	102
7A: 50 N KAS	80	-71	-2	13	-18	3
8A: 100 N KAS	130	-97	-3	14	-24	21
9A: 50 N MAR	80	-65	-2	15	-18	10
10A 100 N MAR	130	-90	-3	18	-26	29
11A 150 N MAR	180	-116	-2	27	-33	57
LSD (95 %)		5.2	8.7	7.9	5.0	
Uncropped during winter:						
1B: 100 N NOV	162	-49	-85	24	-31	22
2B: 100 N NOV+	168	-50	-64	22	-30	47
3B: 50 N KAS	80	-69	-30	23	-30	-26
4B: 100 N KAS	130	-94	-36	24	-29	-4
5B: 100 N MAR	130	-83	-40	29	-35	2
LSD(95 %)		4.5	11.5	9.6	6.3	

Table A7. Nitrogen balance, SEP 1990 - SEP 1991, kg/ha.

Treatment	N added	N retained	N leached	N_{min} 90	N_{min} 91	Balance
Catch-crop of rye grass:						
1A: Basic dress	30	-33	-5	15	-25	-17
2A: 50 N SEP	81	-47	-7	19	-27	19
3A: 100 N SEP	132	-57	-16	24	-35	48
4A: 50 N NOV	80	-46	-15	24	-36	7
5A: 100 N NOV	129	-55	-13	21	-39	43
6A: 150 N NOV	179	-60	-34	24	-43	66
7A: 50 N KAS	80	-47	-7	18	-26	17
8A: 100 N KAS	130	-66	-11	24	-40	38
9A: 50 N MAR	74	-44	-5	18	-28	15
10A 100 N MAR	119	-58	-8	26	-36	42
11A 150 N MAR	163	-77	-10	33	-48	61
LSD (95%)		4.5	9.6	5.0	8.8	
Uncropped during winter:						
1B: 100 N NOV	129	-25	-90	31	-26	18
2B: 100 N NOV+	139	-27	-91	30	-27	23
3B: 50 N KAS	80	-37	-60	30	-30	-17
4B: 100 N KAS	130	-48	-58	29	-38	15
5B: 100 N MAR	119	-45	-68	35	-40	0
LSD (95%)		3.7	10.3	6.3	8.9	

Table A8. Accumulated nitrogen balance, SEP 1988 - SEP 1991, kg/ha.

Treatment	N added	N retained	N leached	N_{min} 88	N_{min} 91	Balance
Catch-crop of rye grass:						
1A: Basic dress	90	-116	-12	10	-25	-53
2A: 50 N SEP	263	-158	-17	10	-27	70
3A: 100 N SEP	436	-205	-32	10	-35	174
4A: 50 N NOV	255	-166	-27	10	-36	36
5A: 100 N NOV	418	-195	-39	10	-39	155
6A: 150 N NOV	582	-214	-100	10	-43	235
7A: 50 N KAS	240	-162	-14	10	-26	49
8A: 100 N KAS	390	-220	-18	10	-40	122
9A: 50 N MAR	232	-154	-11	10	-28	49
10A 100 N MAR	376	-209	-16	10	-36	125
11A 150 N MAR	518	-268	-18	10	-48	194
LSD (95%)		12	15		9	
Uncropped during winter:						
1B: 100 N NOV	428	-108	-274	10	-26	30
2B: 100 N NOV+	440	-113	-212	10	-27	97
3B: 50 N KAS	240	-148	-121	10	-30	-48
4B: 100 N KAS	390	-196	-125	10	-38	41
5B: 100 N MAR	376	-182	-139	10	-40	25
LSD (95%)		6	22		9	

Table A9. Potassium balance, SEP 1988 - SEP 1989, kg/ha

Treatment	K added	K retained	K leached	K_{min} 88	K_{min} 89	Balance
Catch-crop of rye grass:						
1A: Basic dress	105	-18	-36	303	-321	33
2A: 50 N SEP	138	-24	-36	303	-365	17
3A: 100 N SEP	165	-30	-37	303	-376	26
4A: 50 N NOV	136	-25	-34	303	-333	47
5A: 100 N NOV	160	-32	-42	303	-359	30
6A: 150 N NOV	185	-37	-43	303	-409	0
7A: 50 N KAS	105	-22	-32	303	-321	33
8A: 100 N KAS	105	-26	-36	303	-292	54
9A: 50 N MAR	129	-22	-31	303	-339	40
10A 100 N MAR	148	-31	-37	303	-388	-6
11A 150 N MAR	166	-37	-40	303	-388	4
LSD (95 %)		3.6	9.1		63.2	
Uncropped during winter:						
1B: 100 N NOV	160	-19	-52	303	-363	29
2B: 100 N NOV+	163	-19	-48	303	-348	51
3B: 50 N KAS	105	-21	-45	303	-331	11
4B: 100 N KAS	105	-26	-45	303	-288	49
5B: 100 N MAR	148	-28	-42	303	-344	37
LSD (95 %)		1.9	9.0		52.0	

Table A10. Potassium balance, SEP 1989 - SEP 1990, kg/ha

Treatment	K added	K retained	K leached	K_{min} 89	K_{min} 90	Balance
Catch-crop of rye grass:						
1A: Basic dress	105	-47	-34	321	-366	-20
2A: 50 N SEP	149	-67	-36	365	-466	-54
3A: 100 N SEP	187	-88	-33	376	-422	19
4A: 50 N NOV	143	-72	-27	333	-431	-54
5A: 100 N NOV	175	-79	-38	359	-419	-3
6A: 150 N NOV	207	-75	-40	409	-478	23
7A: 50 N KAS	105	-74	-31	321	-318	4
8A: 100 N KAS	105	-101	-28	292	-319	-51
9A: 50 N MAR	139	-68	-29	339	-410	-29
10A 100 N MAR	167	-92	-29	388	-457	-22
11A 150 N MAR	195	-114	-22	388	-491	-44
LSD (95 %)		8.6	8.8	63.2	69.3	
Uncropped during winter:						
1B: 100 N NOV	175	-50	-61	363	-471	-42
2B: 100 N NOV+	175	-50	-63	348	-478	-68
3B: 50 N KAS	105	-71	-37	331	-354	-25
4B: 100 N KAS	105	-93	-34	288	-306	-39
5B: 100 N MAR	167	-85	-31	344	-455	-61
LSD (95 %)		4.6	21.3	52.0	38.0	

Table A11. Potassium balance, SEP 1990 - SEP 1991, kg/ha.

Treatment	K added	K retained	K leached	K_{min} 90	K_{min} 91	Balance
Catch-crop of rye grass:						
1A: Basic dress	105	-19	-35	366	-376	41
2A: 50 N SEP	123	-25	-41	466	-429	94
3A: 100 N SEP	135	-30	-49	422	-477	2
4A: 50 N NOV	132	-25	-40	431	-405	94
5A: 100 N NOV	154	-29	-46	419	-479	20
6A: 150 N NOV	176	-34	-61	478	-551	8
7A: 50 N KAS	105	-24	-32	318	-366	0
8A: 100 N KAS	105	-30	-29	319	-352	13
9A: 50 N MAR	124	-46	-32	410	-414	42
10A 100 N MAR	137	-30	-30	457	-456	78
11A 150 N MAR	150	-41	-30	491	-506	64
LSD (95%)		17.9	6.2	69.3	52.1	
Uncropped during winter:						
1B: 100 N NOV	154	-22	-79	471	-396	127
2B: 100 N NOV+	154	-22	-73	478	-398	139
3B: 50 N KAS	105	-30	-41	354	-304	84
4B: 100 N KAS	105	-30	-38	306	-265	78
5B: 100 N MAR	137	-41	-45	455	-384	122
LSD (95%)		6.3	9.6	38.0	27.5	

Table A12. Accumulated potassium balance, SEP 88-SEP 91, kg/ha.

Treatment	K added	K retained	K leached	K_{min} 88	K_{min} 91	Balance
Catch-crop of rye grass:						
1A: Basic dress	315	-84	-104	303	-376	54
2A: 50 N SEP	410	-115	-112	303	-429	57
3A: 100 N SEP	487	-148	-119	303	-477	46
4A: 50 N NOV	411	-122	-101	303	-405	86
5A: 100 N NOV	489	-140	-126	303	-479	47
6A: 150 N NOV	568	-146	-144	303	-551	31
7A: 50 N KAS	315	-120	-95	303	-366	37
8A: 100 N KAS	315	-157	-93	303	-352	16
9A: 50 N MAR	392	-136	-92	303	-414	53
10A 100 N MAR	452	-153	-96	303	-456	50
11A 150 N MAR	511	-192	-92	303	-506	24
LSD (95%)		17	12		52	
Uncropped during winter:						
1B: 100 N NOV	489	-90	-192	303	-396	113
2B: 100 N NOV+	492	-90	-185	303	-398	123
3B: 50 N KAS	315	-121	-123	303	-304	70
4B: 100 N KAS	315	-148	-117	303	-265	88
5B: 100 N MAR	452	-154	-118	303	-384	99
LSD (95%)		9	31		28	

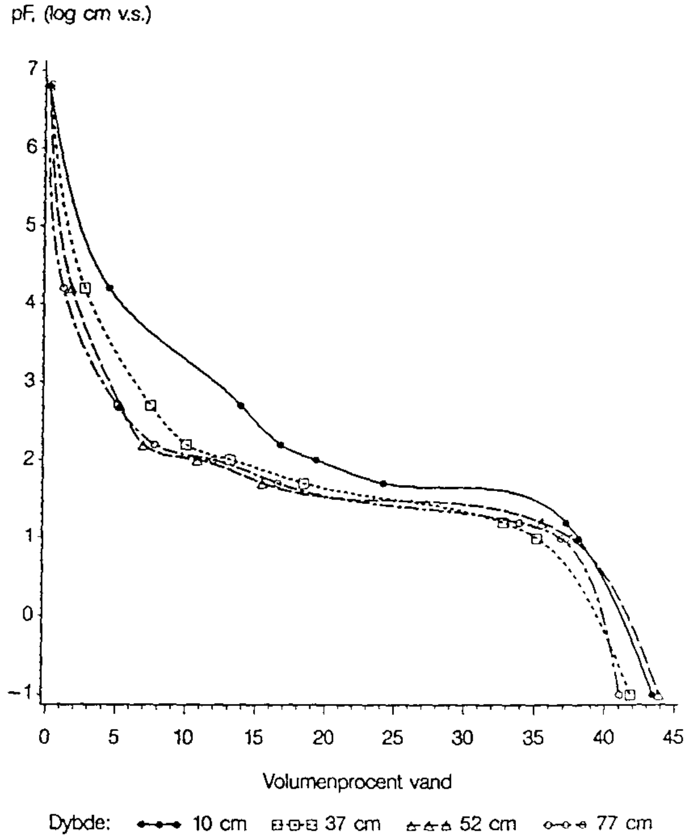

Fig. 1 Retention's curves.
Volume-percent water versus pF (log cm water column) at different depth.

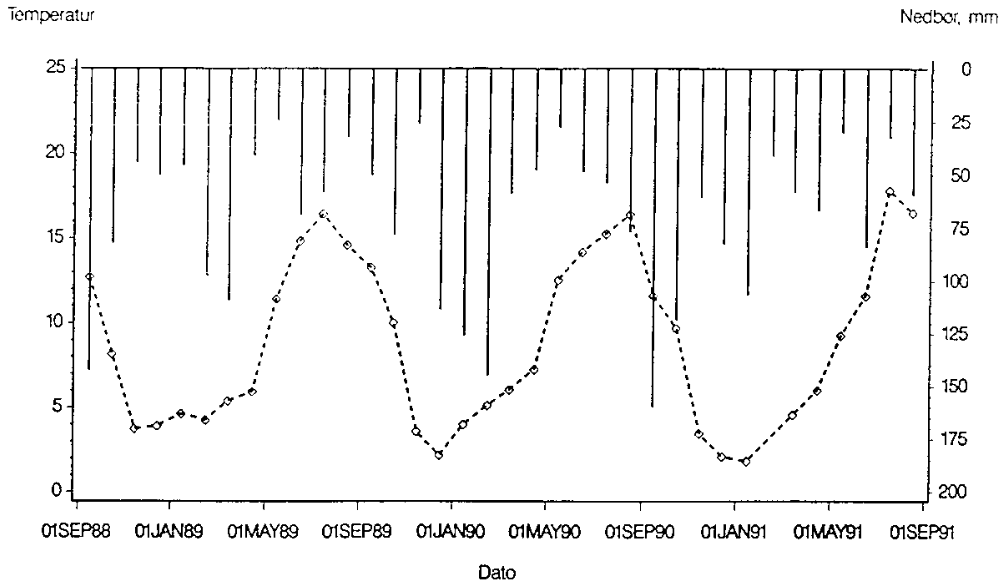

Fig. 2. Average local temperature and rainfall.
Temperature in Celsius and rainfall in mm versus time. The observations are averaged monthly.

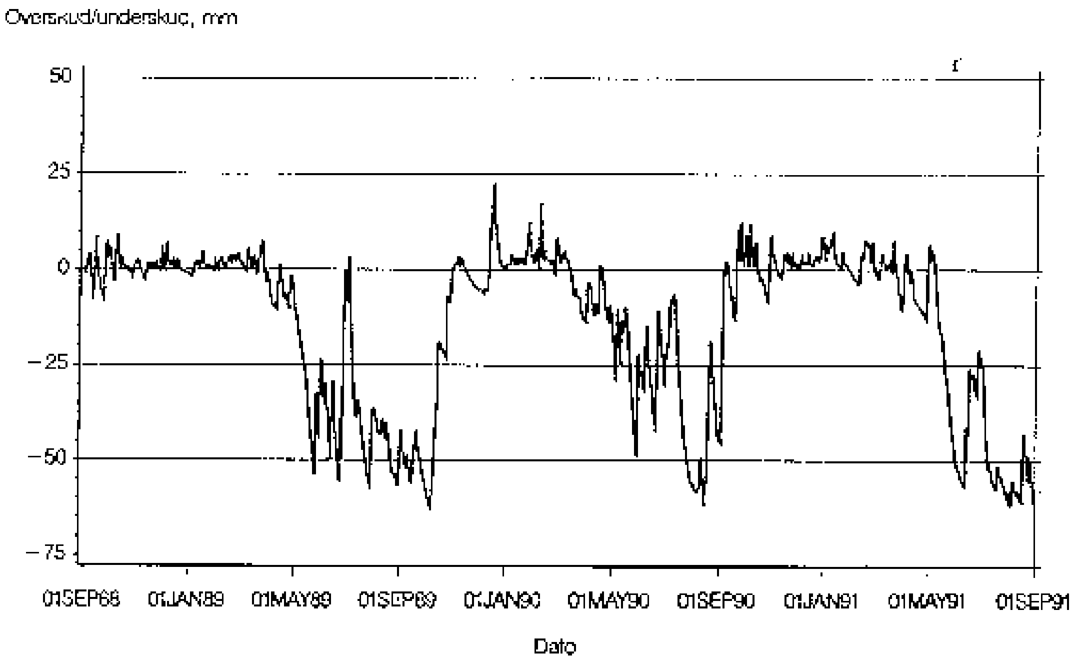

Fig. 3 The water contents of the root zone.
The water content of the root zone versus field capacity (surplus/deficit, mm) over time.
The crop is spring barley with ray grass catch crop.

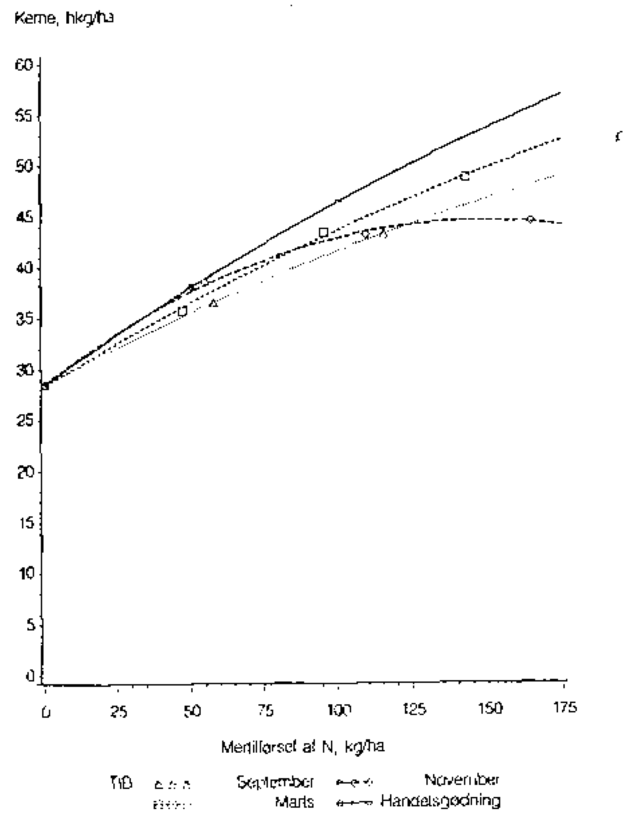

Fig. 4. Grain yields hkg/ha versus quantity of potato juice.
The plots have all received 30 kg N per ha as artificial fertilizer + additional 50, 100 or 150 kg as potato juice.

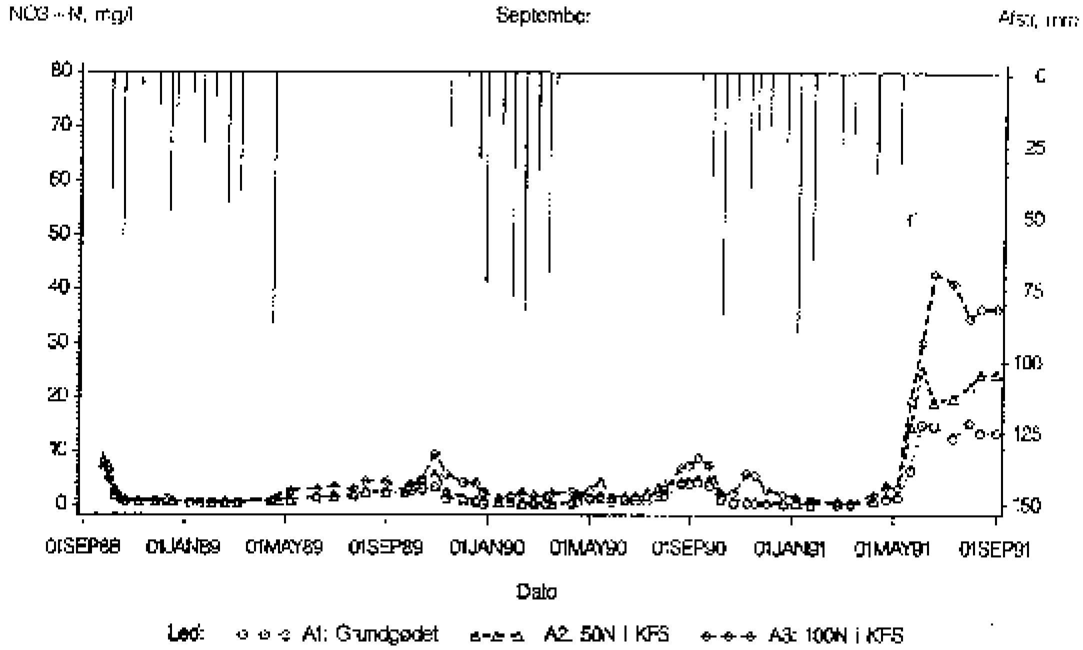

Fig. 5a. Nitrate concentration in soil water
Concentrations of nitrate nitrogen mg/l 80 cm below surface and calculated drain of water in mm. All plots with rye grass as catch crop.

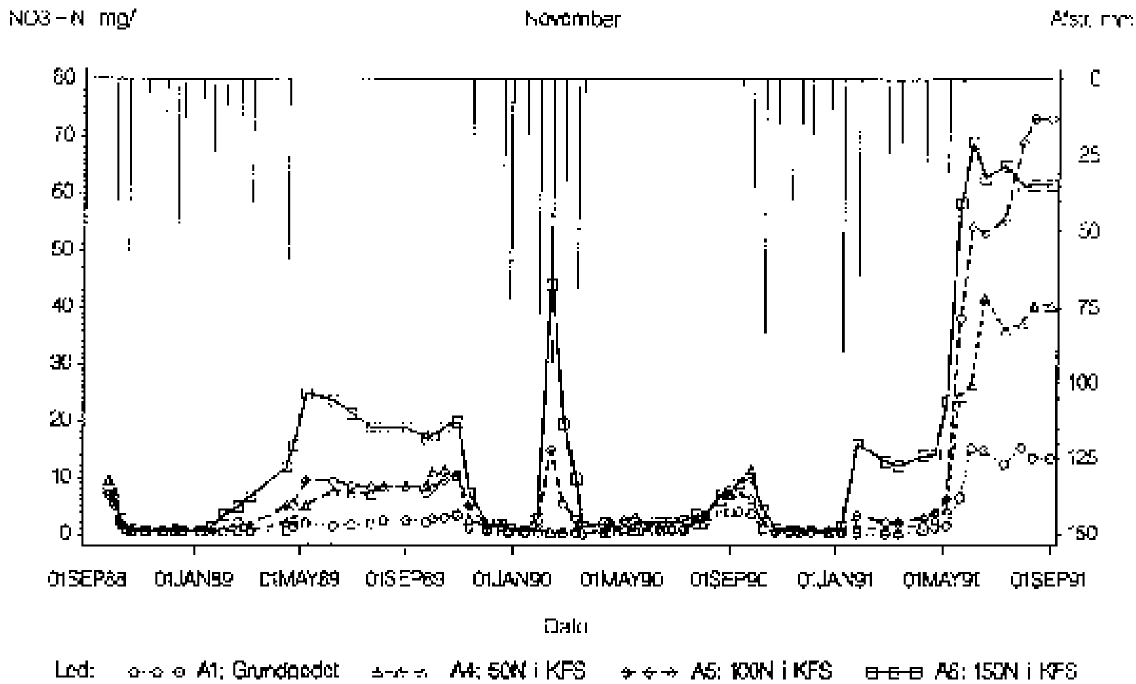

Fig. 5b. Concentration of nitrate in soil water.
The graph shows the effect of potato juice given in November.

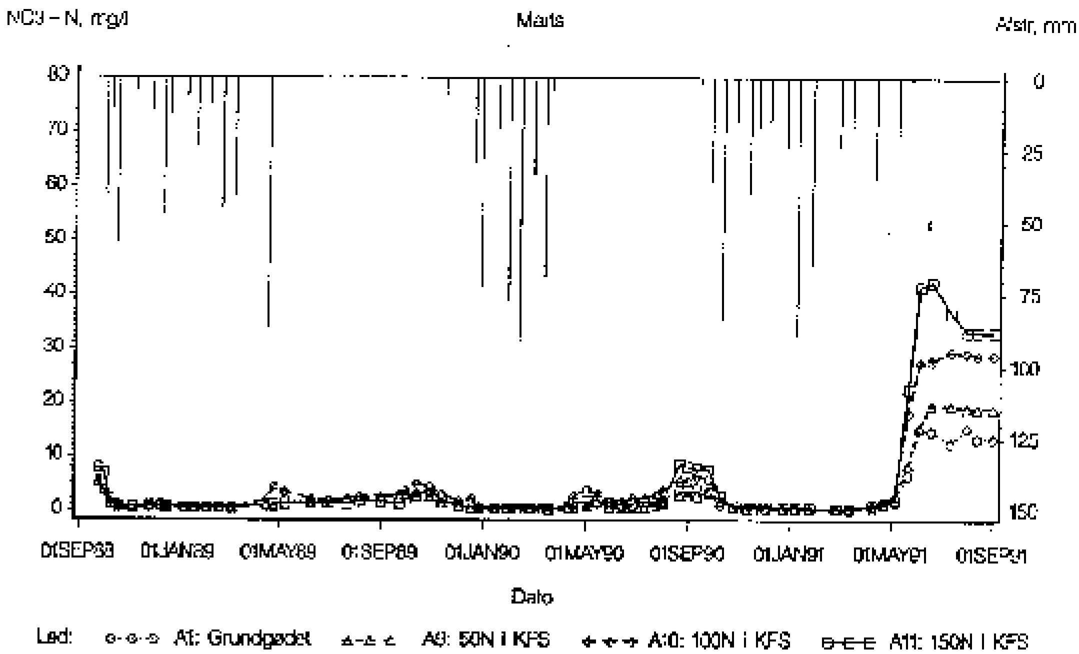

Fig. 5c. Concentration of nitrogen in soil water.
The effect of potato juice in March before sowing spring barley after rye grass catch crop.

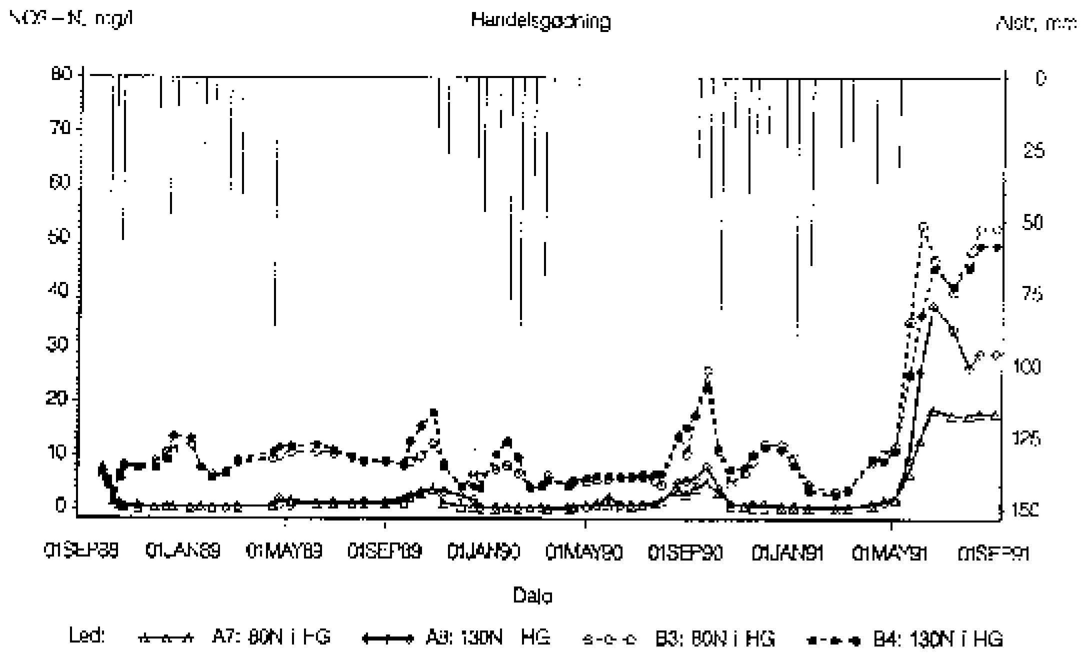

Fig. 5d. Concentration of nitrogen in soil water.
The effect of artificial fertilizer in March.
Group A is with spring barley after rye grass catch crop and group B is spring barley after uncropped fields.

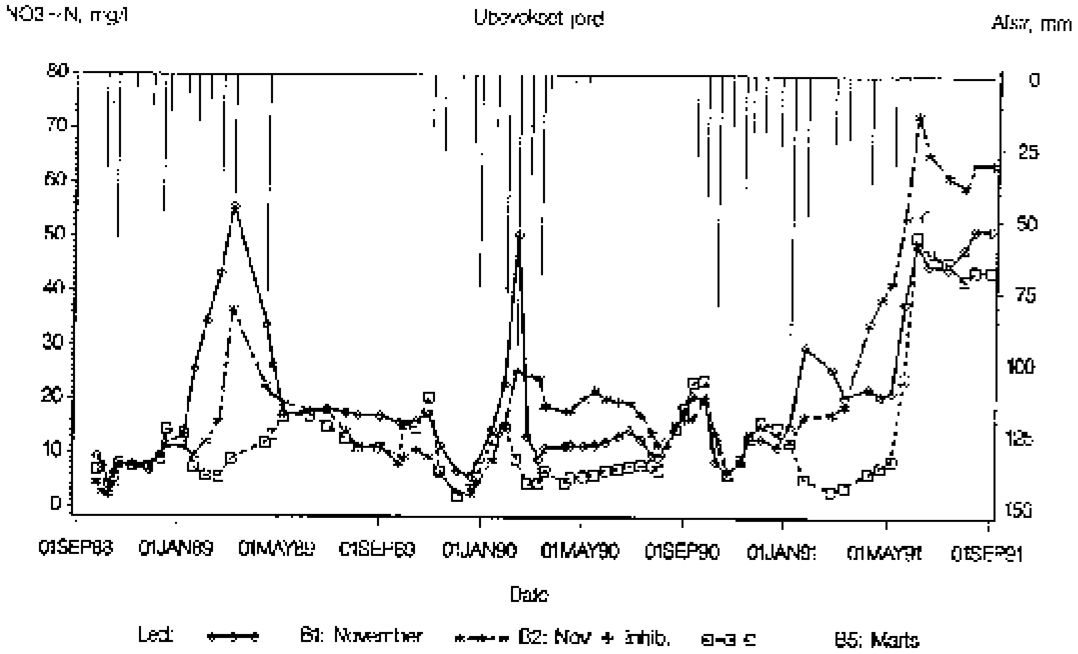

Fig. 5e. Concentration of nitrate in soil water.
The effect of potato juice on uncropped soil during winter. B2 is test of potato juice with nitrification inhibitor.

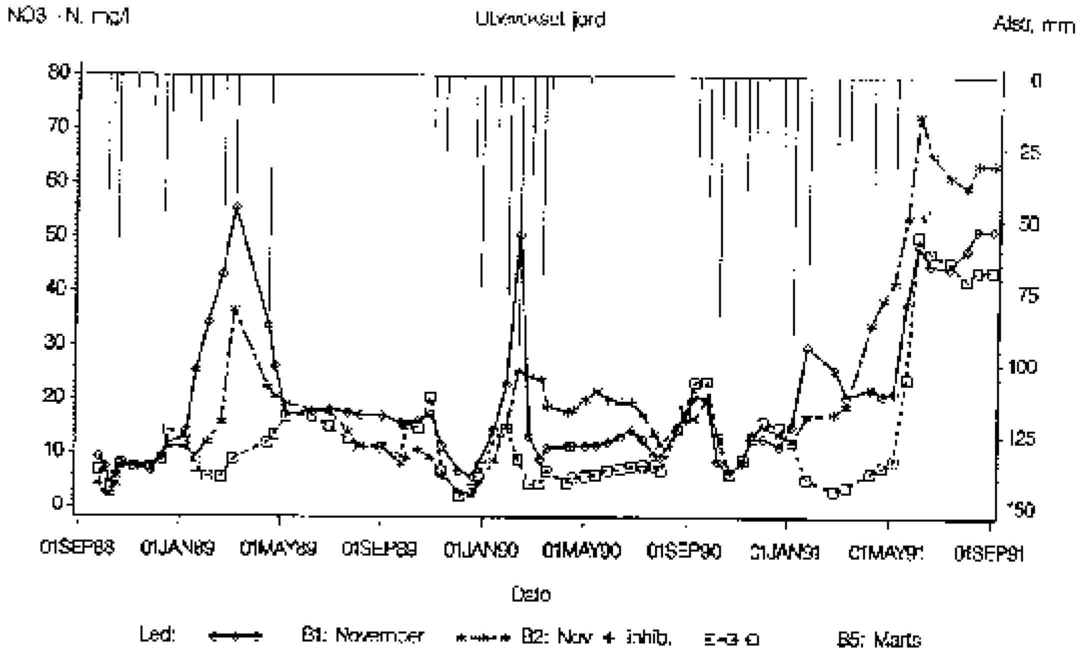

Fig. 5f. Concentration of nitrate in soil water.
The effect of potato juice equivalent to 100 kg N/ha on rye grass catch crop at different time.

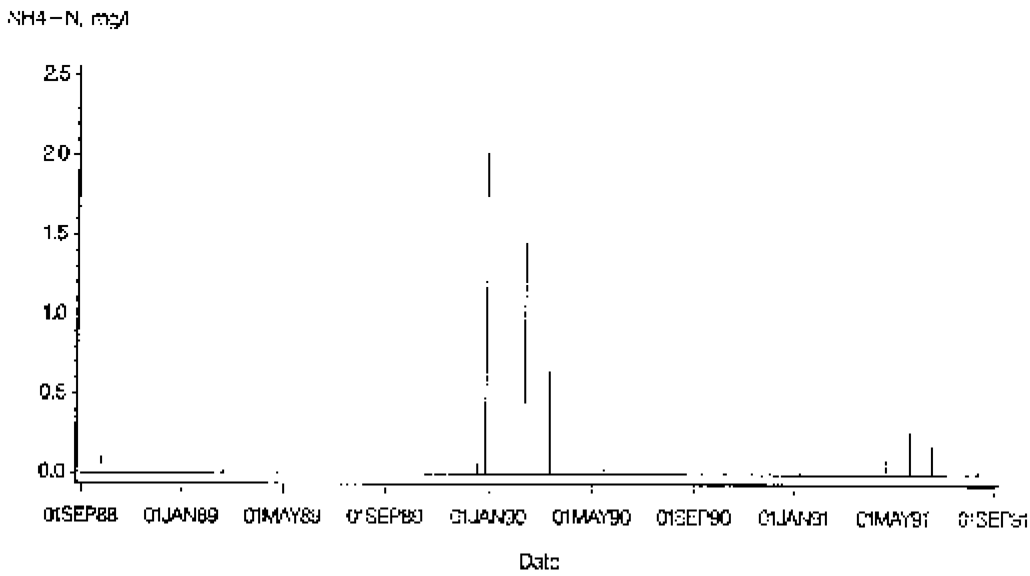

Fig. 6 Concentration of ammonium in soil water.
The concentration of ammonium nitrogen 80 cm below surface after potato juice with nitrification inhibitor (100 kg N/ha).

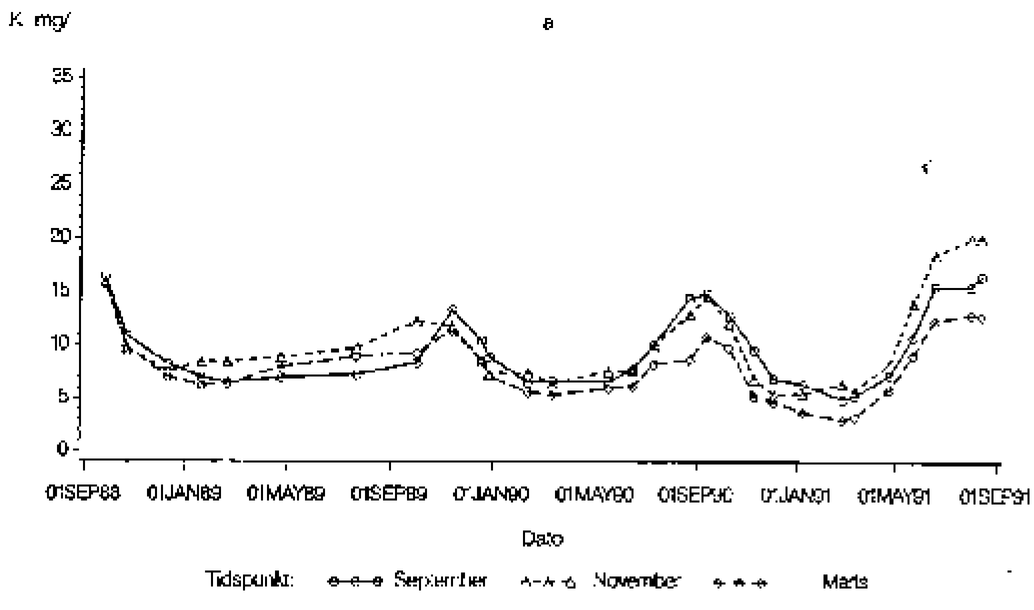

Fig. 7a. Concentration of potassium in soil water.
The effects on potassium concentration mg/l in soil water 80 cm below surface versus time of application. Graph shows joint results of 50 and 100 kg N/ha.

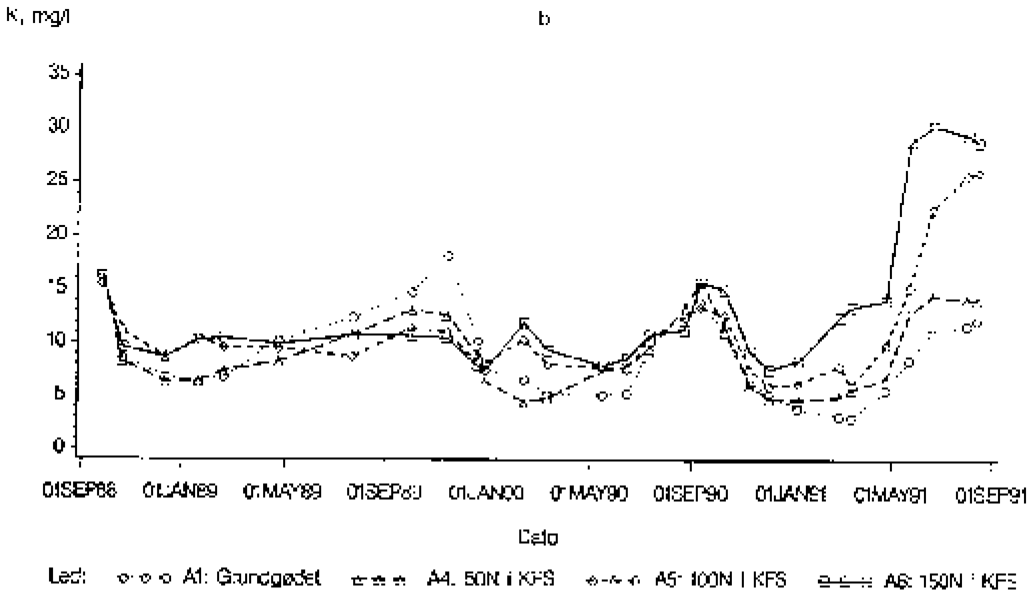

Fig. 7b. Concentration of potassium in soil water. *Potassium concentration (K mg/l) after different quantities of potato juice in November on rye grass catch crop. A1 did not receive potato juice.*

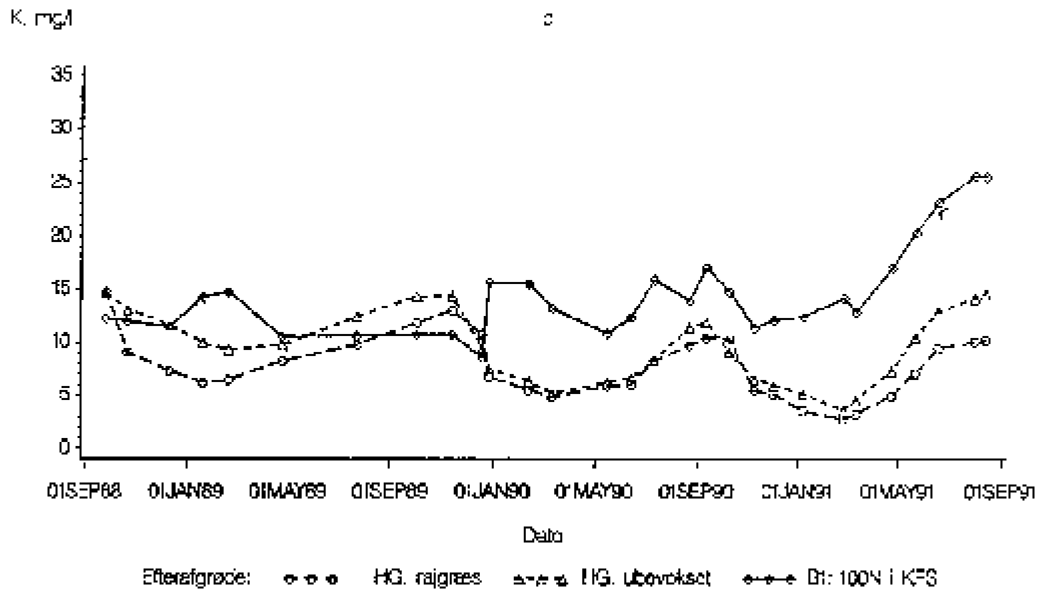

Fig. 7c. Concentration of potassium in soil water.
The effect of artificial fertilizer in March and potato juice (100 kg N/ha) in November.
HG = average of two levels of artificial fertilizer.

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