EFFECT OF IRRIGATION AND MINERAL FERTILIZATION ON SPRING CEREALS CULTIVATED ON A SANDY SOIL.

Part III. SOME PHYSICAL AND CHEMICAL SOIL PROPERTIES

Adam Kocmit[1], Irena Zbiec[2], Tomasz Tomaszewicz[1] and Cezary Podsiadlo[2]

ABSTRACT

Overhead irrigation affected the soil water management, annealing the water ascent, and creating the possibility of run - off water containing dissolved substances. The applied irrigation destroyed also the soil aggregates, causing destruction of its structure and increasing its density. High doses of mineral fertilizers combined with irrigation, increased the soil nutrient content, thus enhancing the plant physiological processes, and later exchangeable sorption processes. The active H^+ kation, entering the soil sorption complex, replaces other ions which become easy accessible for the plants and also mobile in the soil. As effect of the applied treatment, the contents of NO_3 and NH_4, soil pH and sorption properties were altered, thus such management meant to enhance plant production may cause a decrease of soil fertility and harm the enviroument.

Key words*:* irrigation, NPK fertilization, sandy soil properties

INTRODUCTION

Supplemental irrigation and high mineral fertilization are applied to increase the fertility and productivity of sandy soils but one should also consider the possibility of negative effects of these measures. Irrigation doses which exceed the soil capacity can cause a migration of soil solution within or even out of the soil profile and accumulation of minerals in the ground water. Water, migrating through the soil, enriched by minerals from fertilizers enhances the ion exchange which, combined with the plant physiological processes, leads to acidification of the soil liquid phase. Many authors (Borowiec et al., 1978, Borowiec et al., 1981, Borowiec and Zablocki, 1988; Chudecki et al., 1970, Kopec et al., 1991, Meissner et al., 1991, Michel et al., 1991, Muller et al., 1991, Smukalaski and Rogasik, 1991) confirm the above statement.

Changes of the liquid-gaseous phase of sandy soils, caused by overhead irrigation, which affect the soil fertility, so far are not fully understood and the reports often controversial. Yield increases caused by fertilization and irrigation are remarkable, and the remaining after-harvest plant residues are a source of organic matter, which intensifies the soil microbial activity, thus contributing to soil fertility enhancement. This study aims at describing the effects of overhead irrigation and mineral fertilization on some physical and chemical properties of a sandy soil. The results may also describe the influence of these effects on soil fertility and the environment.

MATERIALS AND METHODS

The field experiment design has been described in the part I of this study.

For the pedological research, samples were taken from the following combinations: non irrigated and irrigated, both without NPK and fertilized with 450 kg NPK/ha. Soil samples were of two kinds: one consisting of loose soil taken from 2 pits dug March 23.1992, and from 110 cm drills taken May 14, June 1, and 30, Sept.2, Oct.9, Nov.13. The other samples consisted of 100 cm^3 intact soil, taken from 2 pits, and later on at the above mentioned dates, from 0-15, 15-30, 30-45 cm soil layers.

These samples were analysed as follows: mechanical composition by areometric Casagrande method, modyfied by Proszynski; water capacity (present, capillary, total), volume density - by weight; specific density - by piknometry. On the basis of the above features, the water reserves were calculated: present, soil - bound (WTWR), inaccessible for plants, also the soil porosity, of the chemical soil properties, pH_{KCl}, sorption (Hh and S) by Kappen, exchangeable Ca and Mg in $1M CH_3COONH_4$, A1 and H cations by Sokolow, $N\text{-}NO_3$ and NH_4 in 0.03M CH_3COOH by potentiometry. The results are presented in

[1] Department of Soil Erosion and Recultivation, Agricultural University of Szczecin, Poland
[2] Department of Plant Production and Irrigation, Agricultural University of Szczecin, Poland

kg/ha for 25 and 125 cm soil layers of $1m^2$ base.

RESULTS AND DISCUSSION

Physical soil properties. In 1992, because of rain deficiency the nonirrigated soil quickly lost the water accumulated in winter, and in May had water reserve below wilting point. The plants suffered water deficit troughout the whole soil profile. Calculations taking into account water income from rain, potential losses by evaporation in April, and evapotranspiration in May (Tables 1 and 2), have shown that by the first 10-day period in May, trough the soil leaked 14.5-44.5 mm water, and by the end of May, the water run-off during 6-7 weeks amounted to 125.4 and 142.8 mm.

The presented data characterise the water management in a sandy soil cultivated by casual agrotechnique, show that this soil suffers water deficit as early as in May. Such conditions not only have a negative impact on the plants, but also cause an inhibition of water run-off. At the same time the capillary ascent which goes on also in June, gains significance, thus the water moves upwards. As can be seen in table 1, the amount of ascending water may reach 38 and 41 mm in the whole profile. If the water supply is low, rises the concentration of minerals in the soil solution, particu-

Table.1 Approximate water balance in a 0-110 cm non irrigated sandy soil

Months	Dec-ade	Present water reserve (mm) in 0-100 cm profile		Pre-cipi-tatio (mm)	Evapo-ration losses*	Water balance								
						Water income (mm)		Evapo ration losses	Theoretical soil content (mm)		Water run-off (mm)		Water ascent (mm)	
		Profile1 (0NPK/ha)	Profile 2 (450NPK/ha)			Profil 1	Profil 2		Profil 1	Profil 2	Profil 1	Profil 2	Profil 1	Profil 2
March	III	265.5	242.5	37.9	-	-	-	-	-	-	-	-	-	-
April	I-III	-	-	23.2	58	-	-	-	-	-	-	-	-	-
May	I	-	-	27.1	23	353.7	330.7	81.0	272.7	249.7	14.5	44.5	-	-
	II	258.2	205.2	7.8	24	-	-	-	-	-	-	-	-	-
	III	86.7	81.1	0.0	27	361.5	338.5	123.0	229.5	206.5	142.8	125.4	-	-
June	I	-	-	11.8	28	-	-	-	-	-	-	-	-	-
	II	-	-	2.4	28	-	-	-	-	-	-	-	-	-
	III	56.2	53.8	0.0	27	375.5	352.7	215.0	160.7	137.7	104.5**	83.9**	38.3	41.5

* Agroclimatical principles of water amelioration in Poland, ed.PWRIL, 1982
** Decline of water losses from soil, caused by ascending soil solutions

Table 2. Approximate water balance in a 0-110 cm irrigated sandy soil

Months	Dec-ades	Present water reserve(mm) in 0-100 cm profile		Precipi-tation (mm)	Water-ing doses (mm)	Evapo-ration losses (mm)	Water balance						
							Water income (mm)		Evapora-tion losses (mm)	Theoretical con-tent (mm)		Approximate water ascent (mm)	
		Profile 1 (0 NPK/ha)	Profile 2 (450 NPK/ha)				Profil 1	Profil 2		Profil 1	Profil 2	Profil 1	Profil 2
March	III	265.5	242.5	37.9	-	-	-	-	-	-	-	-	-
April	I-III	-	-	23.2	-	58	-	-	-	-	-	-	-
	I	-	-	27.1	-	23	353.7	330.7	81	272.7	249.7	63.3	36.5
May	II	209.4	213.2	7.8	20	24	-	-	-	-	-	-	-
	III	196.0	159.7	0.0	40	27	421.5	398.5	132	289.5	266.5	202.8* 93.5** 109.3***	185.4* 106.8** 78.6***
June	I-III	167.1	164.8	14.2	100	83	535.7	512.7	215	320.7	297.7	264.5* 153.6** 110.9***	243.9* 132.9** 111.0***

* Difference between theoretical water in watered soil (tab.2) and present soil reserve in nonwatered soil (tab.1)
** Difference between theoretical water content in watered soil (tab.2) and present soil reserve
*** Difference of water run-off between profiles: nonwatered and watered (amount of water which, taking part in vertical movement through the soil, enhances its flushing)

larly by high fertilizer doses, hence a diminished soil fertility. In the non irrigated soil, its compression is lessened (Table 4), thus the soil porosity rose, particularly the noncapillary pores, which enhances soil aeration.

Beside enhancing the water reserve which eliminates plant deficit, irrigation also influences the soil water management. During a drought period, when the non irrigated soil dryed out, the irrigated plots contained some water (110.9 and 111.0 mm), which could leach (Table 3).

Thus the soil leaching period was prolonged and the caplillary ascent stopped.

Migrating water affects the soil aggregates. Since their water resistance is low, the soil structure can be destroyed and the soil becomes more compact. This phenomenon was expressed by increased volume density and capillary porosity, and diminished noncapillary porosity in the 45-cm soil layer (Table 4).

Chemical soil properties. The pH of soil liquid is a sensitive indicator of its chemical properties (Figure 1). The pH value depends on applied agricultural measures, particularly NPK fertilization. Irrigation caused acidification, whereas NPK increased the pH. Irrigation acted similar to rainfall, such effects

Talbe 3. Basic physical properties of the upper (0-45 cm) soil layer in June 1992

Soil	Layer thickness (cm)	Volume density So (g/cm^3)		Toal porosity Po (%)		Capillary porosity Pk (%)		Percentage of Pk in Po (100%)	
01.06.1992									
irrigated	0-15	1.50		42.5		36.5		16.3	
	15-30	1.51	1.52	42.2	41.9	36.3	36.6	13.9	13.3
	30-45	1.56		40.9		36.9		9.8	
non irrigated	0-15	1.36		47.9		38.4		19.8	
	15-30	1.45	1.39	44.4	46.7	32.1	34.4	27.8	26.4
	30-45	1.37		47.9		32.7		31.7	
30.06.1992									
irrigated	0-15	1.55		40.6		37.0		9.9	
	15-30	1.60	1.63	38.7	37.8	35.7	33.7	7.8	11.6
	30-45	1.74		34.1		28.3		17.0	
non irrigated	0-15	1.58		39.5		41.1		0.0	
	15-30	1.70	1.62	34.9	38.1	33.8	36.2	3.1	6.1
	30-45	1.59		39.9		33.8		15.2	

Table 4. NO_3^- and NH_4^+ contents in 125 cm soil layer (kg/ha)

Soil profile and depth (cm)	Date of sampling						
	30.III.	14.V.	1.VII.	30.VI.	1.IX.	9.X.	13.XI.
	Combination + NPK + H_2O						
2. 0 - 125	147.0	123.7	93.2	179.7	173.3	226.3	243.2
	Combination + NPK - H_2O						
	147.0	118.5	129.7	186.0	195.1	130.5	194.4
	Combination +NPK + H_2O						
1. 0 - 125	215.4	143.9	68.4	163.9	174.7	214.5	177.2
	Combination +NPK - H_2O						
	215.4	121.9	154.1	219.4	167.4	166.9	198.9

were

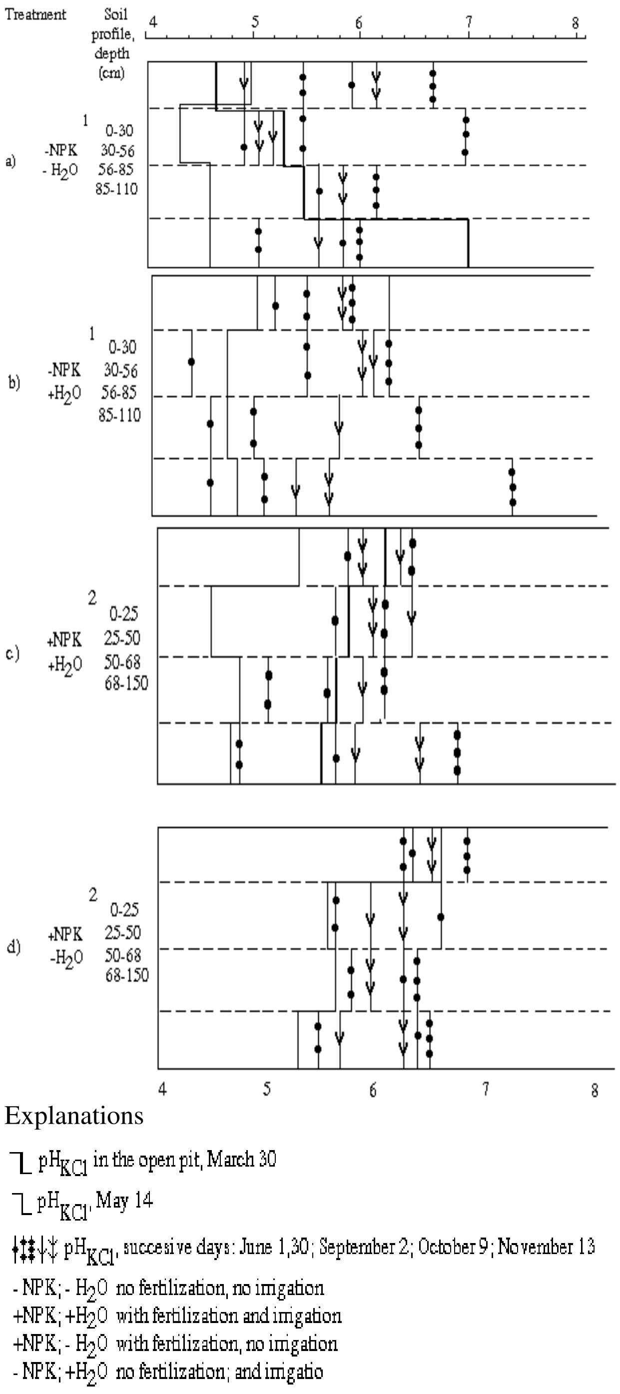

Figure 1. Soil pH_{KCl} in 1992

described by Chudecki et al. (1970), Kac-Kacas and Malinska (1963) because of increased water migration carrying alkaline kations. The increased pH in 85-110 and 68-150 cm (Figure 1b, 1c) soil layers which had been irrigated could be due to the migration. The increased pH (>7) indicates how deep these kations migrate through the soil.

Through the soil migrate ions loosely bound to the sorption complex (NH_4^+, NO_3^-) and exchangeable ions (Ca^{2+} , Mg^{2+}, Al^{3+}, H^+). The mineral forms of nitrogen (NO_3^- , NH_4^+) are particularly prone to oscillation, since their content depends on the plant growth stage, soil leaching etc. Their content varies also during the year (Kac-Kacas and Malinska 1963), (Kopec et al., 1991). Fields irrigated in May and June hold less mineral nitrogen than nonirrigated, on the other hand the lesser plant stand on non irrigated plots consumes less nitrogen.

But that surplus can not stay long in the soil, and in the fall the contents become similar. Thus, high doses of mineral fertilizer aplied on sandy soils not utilized by plants because of drought, may partly leach into ground water.

Increased soil moisture and mineral content changes the ion balance at the soil solid - liquid contact zone, thus activates the exchange sorption, affects the hydrolytic acidity (Hh) and exchangeable bases sum (S) – figure 2.

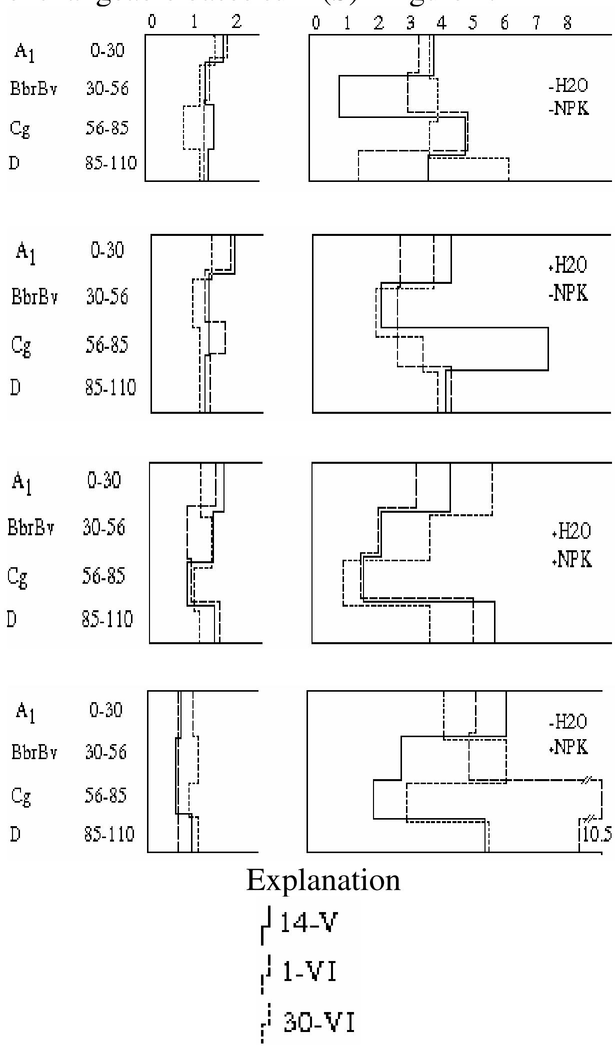

Figure 2. Range of hydrolitic acidity (Hh) and total exchangeable bases (S) changes as affected by the treatments during vegetation peak (May 14 – June 30)

Tabel 5. Exchangeable cations (Ca^{2+} + Mg^{2+} and Al^{3+} + H^{+}) share in the soil exchange capacity (%)

Date	Genetic layer	Combination							
		-NPK_4	-H_2O	-NPK	+H_2O	+NPK	+H_2O	+NPK_4	-H_2O
		Al^{3+} +H^{+}	Ca^{++}+Mg^{++}	Al^{3+} +H^{+}	Ca^{++}+Mg^{++}	Al^{3+} + H^{+}	Ca^{++}+Mg^{++}	Al^{3+}+H^{+}	Ca^{++}+Mg^{+}
14.V.	Ap	3.0	81.0	1.2	86.1	6.2	75.6	1.3	87.9
	BbrBv	8.7	57.6	3.9	86.7	2.1	77.2	2.8	81.8
	Cg	1.3	91.6	2.0	74.6	3.6	76.2	1.6	82.6
	Dg	1.6	85.9	1.3	84.2	1.0	86.7	1.5	87.6
1.VI.	Ap	1.5	81.6	1.6	81.7	1.9	80.6	1.0	87.8
	BbrBv	1.5	74.6	1.8	73.5	1.5	72.4	0.8	82.9
	Cg	2.5	82.6	2.1	75.1	3.0	42.3	1.1	83.5
	Dg	7.3	71.3	1.7	78.9	0.7	83.0	1.9	83.7
30.VI.	Ap	3.3	78.5	2.0	79.9	1.7	85.0	1.5	85.2
	BbrBv	3.2	81.7	3.3	77.1	1.9	81.8	1.6	83.9
	Cg	4.7	74.6	1.4	85.1	9.1	34.7	2.1	81.0
	Dg	2.3	81.5	1.7	82.6	2.3	79.6	1.5	79.8

The active H^{+} ion while entering the sorption complex replaces the alkaline ions which then move freely into deeper soil layers. Besides, these ions can be easily taken up by plant roots. The most dynamic changes of the liquid phase were found in watered and fertilized soil, the range being for Ca^{2+} and Mg^{2+} 34.7-86.7%, for Al^{3+} and H^{+} 0.7-9.1% (Table 5).

CONCLUSIONS

Irrigation affects soil water management: the water stored in deeper layers did not ascend, the plant had sufficient water available, the water surplus could move downwards.

Irrigation applied on heavily fertilized plots, causing better plant growth, increased ion exchange on the surface of soil colloids to a depth of 90-110 cm, which had some negative effects on the soil structure.

Lower pH increased hydrolytic acidity accompanied by a lesser amount of exchangeable bases and Ca, Mg in the soil sorption complex, can be regarded as indices of decreased soil fertility.

Since sandy soils are charaterized by low buffer capacity and poor sorption complex, such measures as supplemental irrigation and high doses of NPK should be adjusted not only to the crop planted, but fine - tuned to the soil conditions, and accompanied by farm manure and calcium application.

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Table.1 Approximate water balance in a 0-110 cm, non irrigated sandy soil.

Months	Decade	Present water reserve (mm) in 0-100cm profile		Precipitatio	Evaporation losses*	Water balance								
						Water income (mm)		Evaporation losses	Theoretical soil content (mm)		Water run-off (mm)		Water ascent (mm)	
		Profile1 (0NPK/ha)	Profile 2 (450NPK/ha)	(mm)		Profil 1	Profil 2		Profil 1	Profil 2	Profil 1	Profil 2	Profil 1	Profil 2
March	III	265.5	242.5	37.9	-	-	-	-	-	-	-	-	-	-
April	I-III	-	-	23.2	58	-	-	-	-	-	-	-	-	-
May	I	-	-	27.1	23	353.7	330.7	81.0	272.7	249.7	14.5	44.5	-	-
	II	258.2	205.2	7.8	24	-	-	-	-	-	-	-	-	-
	III	86.7	81.1	0.0	27	361.5	338.5	123.0	229.5	206.5	142.8	125.4	-	-
June	I	-	-	11.8	28	-	-	-	-	-	-	-	-	-
	II	-	-	2.4	28	-	-	-	-	-	-	-	-	-
	III	56.2	53.8	0.0	27	375.5	352.7	215.0	160.7	137.7	104.5**	83.9**	38.3	41.5

* Agroclimatical principles of water amelioration in Poland, ed.PWRIL, 1982.

** Decline of water losses from soil, caused by ascending soil solutions.

Table 2. Approximate water balance in a 0-110 cm, irrigated sandy soil.

Months	Decades	Present water reserve(mm) in 0-100 cm profile		Precipitation (mm)	Watering doses (mm)	Evaporation losses (mm)	Water balance						
							Water income (mm)		Evaporation losses (mm)	Theoretical content (mm)		Approximate water ascent (mm)	
		Profile 1 (0 NPK/ha)	Profile 2 (450 NPK/ha)				Profil 1	Profil 2		Profil 1	Profil 2	Profil 1	Profil 2
March	III	265.5	242.5	37.9	-	-	-	-	-	-	-	-	-
April	I-III	-	-	23.2	-	58	-	-	-	-	-	-	-
	I	-	-	27.1	-	23	353.7	330.7	81	272.7	249.7	63.3	36.5
May	II	209.4	213.2	7.8	20	24	-	-	-	-	-	-	-
	III	196.0	159.7	0.0	40	27	421.5	398.5	132	289.5	266.5	202.8* 93.5** 109.3***	185.4* 106.8** 78.6***
June	I-III	167.1	164.8	14.2	100	83	535.7	512.7	215	320.7	297.7	264.5* 153.6** 110.9***	243.9* 132.9** 111.0***

*Difference between theoretical water in watered soil (tab.2) and present soil reserve in nonwatered soil (tab.1)
** Difference between theoretical water content in watered soil (tab.2) and present soil reserve
*** Difference of water run-off between profiles:nonwatered and watered (amount of water which, taking part in vertical movement through the soil, enhances its flushing)

Tabel 3. Basic physical properties of the upper (0-45 cm) soil layer in June 1992.

Soil	Layer thickness (cm)	Volume density So (g/cm^3)		Toal porosity Po (%)		Capillary porosity Pk (%)		Percentage of Pk in Po (100%)	
01.06.1992 r									
irrigated	0-15	1.50		42.5		36.5		16.3	
	15-30	1.51	1.52	42.2	41.9	36.3	36.6	13.9	13.3
	30-45	1.56		40.9		36.9		9.8	
non irrigated	0-15	1.36		47.9		38.4		19.8	
	15-30	1.45	1.39	44.4	46.7	32.1	34.4	27.8	26.4
	30-45	1.37		47.9		32.7		31.7	
30.06.1992 r.									
irrigated	0-15	1.55		40.6		37.0		9.9	
	15-30	1.60	1.63	38.7	37.8	35.7	33.7	7.8	11.6
	30-45	1.74		34.1		28.3		17.0	
non irrigated	0-15	1.58		39.5		41.1		0.0	
	15-30	1.70	1.62	34.9	38.1	33.8	36.2	3.1	6.1
	30-45	1.59		39.9		33.8		15.2	

Table 4. NO_3^- and NH_4^+ contents in 125 cm soil layer (kg/ha).

Soil profile and depth (cm)	Date of sampling						
	30.III.	14.V.	1.VII.	30.VI.	1.IX.	9.X.	13.XI.
2. 0 - 125	Combination + NPK + H_2O						
	147.0	123.7	93.2	179.7	173.3	226.3	243.2
	Combination + NPK - H_2O						
	147.0	118.5	129.7	186.0	195.1	130.5	194.4
1. 0 - 125	Combination +NPK + H_2O						
	215.4	143.9	68.4	163.9	174.7	214.5	177.2
	Combination +NPK - H_2O						
	215.4	121.9	154.1	219.4	167.4	166.9	198.9

Tabel 5. Exchangeable cations (Ca^2+ + Mg^2+ and Al^{3+} + H^+) share in the soil exchange capacity (%).

Date	Genetic layer	Combination							
		$-NPK_4$	$-H_2O$	$-NPK_4$	$+H_2O$	$+NPK_4$	$+H_2O$	$+NPK_4$	$-H_2O$
		Al^{3+} +H^+	Ca^{++}+Mg^{++}	Al^{3+} +H^+	Ca^{++}+Mg^{++}	Al^{3+} + H^+	Ca^{++}+Mg^+	Al^{3+}+H	Ca^{++}+Mg^{++}
14.V.	Ap	3.0	81.0	1.2	86.1	6.2	75.6	1.3	87.9
	BbrBv	8.7	57.6	3.9	86.7	2.1	77.2	2.8	81.8
	Cg	1.3	91.6	2.0	74.6	3.6	76.2	1.6	82.6
	Dg	1.6	85.9	1.3	84.2	1.0	86.7	1.5	87.6
1.VI.	Ap	1.5	81.6	1.6	81.7	1.9	80.6	1.0	87.8
	BbrBv	1.5	74.6	1.8	73.5	1.5	72.4	0.8	82.9
	Cg	2.5	82.6	2.1	75.1	3.0	42.3	1.1	83.5
	Dg	7.3	71.3	1.7	78.9	0.7	83.0	1.9	83.7
30.VI.	Ap	3.3	78.5	2.0	79.9	1.7	85.0	1.5	85.2
	BbrBv	3.2	81.7	3.3	77.1	1.9	81.8	1.6	83.9
	Cg	4.7	74.6	1.4	85.1	9.1	34.7	2.1	81.0
	Dg	2.3	81.5	1.7	82.6	2.3	79.6	1.5	79.8

fig 1

fig 2

Table 2. Approximate water balance in a 0-110 cm, irrigated sandy soil

Months	Decades	Present water reserve(mm) in 0-100 cm profile		Precipitation (mm)	Watering doses (mm)	Evaporation losses (mm)	Water balance: Water income (mm)		Evaporation losses (mm)	Theoretical content (mm)		Approximate water ascent (mm)	
		Profile 1 (0 NPK/ha)	Profile 2 (450 NPK/ha)				Profil 1	Profil 2		Profil 1	Profil 2	Profil 1	Profil 2
March	III	265.5	242.5	37.9	-	-	-	-	-	-	-	-	-
April	I-III	-	-	23.2	-	58	-	-	-	-	-	-	-
	I	-	-	27.1	-	23	353.7	330.7	81	272.7	249.7	63.3	36.5
May	II	209.4	213.2	7.8	20	24	-	-	-	-	-	-	-
	III	196.0	159.7	0.0	40	27	421.5	398.5	132	289.5	266.5	202.8* 93.5** 109.3***	185.4* 106.8** 78.6***
June	I-III	167.1	164.8	14.2	100	83	535.7	512.7	215	320.7	297.7	264.5* 153.6** 110.9***	243.9* 132.9** 111.0***

*Difference between theoretical water in watered soil (tab.2) and present soil reserve in nonwatered soil (tab.1)
** Difference between theoretical water content in watered soil (tab.2) and present soil reserve
*** Difference of water run-off between profiles:nonwatered and watered (amount of water which, taking part in vertical movement through the soil, enhances its flushing)

Table 4. NO_3^- and NH_4^+ contents in 125 cm soil layer (kg/ha).

Soil profile and depth (cm)	Date of sampling						
	30.III.	14.V.	1.VII.	30.VI.	1.IX.	9.X.	13.XI.
	Combination + NPK + H_2O						
2. 0 - 125	147.0	123.7	93.2	179.7	173.3	226.3	243.2
	Combination + NPK - H_2O						
	147.0	118.5	129.7	186.0	195.1	130.5	194.4

	Combination +NPK + H_2O						
1. 0 - 125	215.4	143.9	68.4	163.9	174.7	214.5	177.2
	Combination +NPK - H_2O						
	215.4	121.9	154.1	219.4	167.4	166.9	198.9