Theses of doctoral (PhD) dissertation

NUTRIENT TURNOVER STUDIES ON THE CALCAREOUS CHERNOZEM SOIL OF THE HAJDÚSÁG LOESS RIDGE FOR THE ESTABLISHMENT OF GROWING AREA SPECIFIC NUTRIENT MANAGEMENT

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1. INTRODUCTION

The primary aim of companies and farmers dealing with crop production is the achievement of the more productive farming. To fulfil this aim, multi-faceted theoretical and practical knowledge is needed, integrating the crop production technologies of various cultures. The common interacting elements of all technologies are the tillage systems, the biological bases, the nutrient supply, and the plant protection. The practising experts can make farming more profitable by applying former experiences, knowledge and the results of fundamental research. Talking about even fundamental research, a technology employed in the practice or only the detailed investigation of a technological element, the importance of the growing area as the environment of the production is determinant.

The agro-ecological circumstances of the growing area fundamentally limit the possibilities of crop production with respect to each technological element. The appropriate tillage system, the adequate variety, the proper nutrient management, the selection and accomplishment of the effective plant protection require the thorough knowledge of the nature of the growing area.

The possibility for the characterization of the nutrient supply and the nutrient management features of different soils is provided by a classification categorized by growing areas and based on agronomical traits of different soils. The nutrient supply and nutrient management characteristics of soils can differ significantly even when they are in the same growing area category due to the differences in the climatic conditions of the growing area and the level of agrotechnical and nutrient management applied.

As one of the agrotechnical factors, nutrient management is an essential element of farming. In the lack of professional nutrient management, the profitability of the production can decline, since the inappropriate amount and ratio of fertilization can lead to yield decrease, quality decline, uneconomical material consumption, and environmental pressure. By the use of fertilization advisory systems, the nutrient supply of the soils can be preserved and cost-efficient fertilization can be achieved in accordance with the level of production.

The different advisory systems can differ in the applied chemical methods during soil analysis. The different chemical methods can mobilize different amounts of nutrient fractions according to their vigour and the characteristics of the utilized reagents. Some of the methods provide information on the reserves, while others on the amount of nutrient elements available for the plant. Further methods give the opportunity of the study on the reserve mobilization processes. If one likes to form a very precise view about the nutrient supplying ability of the growing area, it would not be enough to know only the reserves or the amount of the directly available nutrient elements, but the direction and intensity of the interchange processes between the two forms. This can be considered as the disadvantages of the chemical methods, since generalization cannot be done on every growing area by the results obtained by one type of soil analyzing technique.

In the Hungarian advisory system, the N-supply has been being determined by the humus content, the growing area categories and the plasticity. Nevertheless, during the N-supply determination based on the humus content, the remaining nitrate amount deriving from the N-fertilizer and the mineralization of organic materials is not taken into consideration, although according to its amount, it can be either nutrient source or environmental risk too.

In foreign countries, the NO_3^-- and NH_4^+ content of the 1-meter layer of the soil is determined according to WEHRMANN and SCHARPF (1979) (N_{min} method). The disadvantage of the method is that it also determines only one parameter, the mineral nitrogen content that can be considerably influenced by the time of sampling, precipitation and fertilization.

The EUF method of NÉMETH (1972) provides the possibility of the soluble and easily oxidisable organic N-fraction beside the fractionation of the mineral nitrogen forms; although the method requires expensive instrumentation and not really applicable for serial analyses.

By the application of 0.01 M potassium chloride as extractant (HOUBA *et al.*, 1990), the soluble and easily oxidisable organic N-fraction can also be determined beside the mineral nitrogen forms, and the method can be employed for serial analyses too. However, the 0.01 M potassium chloride also cannot give information on the amount of reserves.

Similar statements can be taken on the chemical methods applied for the evaluation of the phosphorus and potassium supplements of the growing area. In Hungary, the ammonium lactate-acetic acid (AL) method is widely used for the analysis of the phosphorus and potassium supplements of the soil (EGNÉR *et al.*, 1960). The AL solution dissolves and replaces a part of the reserves besides the easily soluble K content of the soil; thus with this technique, the multiple amount of nutrient elements available for the plants in the soil solution during the growing period is extracted. With the development of agrochemistry, in the second half of the previous century, the advancement of the application of mild extractants (distilled water, diluted salt solutions) was experienced, since tighter correlation was found between the nutrient element content extracted by them and the nutrient supply of the plants.

It is apparent that some chemical methods extract much more nutrient elements from the soil by the more vigorous extractants than the plants can take up. The mild extractants supposedly estimate the amount of nutrient elements directly available for the plants well, but they cannot provide information on the amount of reserves and the velocity of the conversion of them on their own.

2. OBJECTIVES

In my doctoral dissertation I would like to reveal that in what manner are the phosphorus and calcium contents of the soil of the growing area - determined by the traditional, ammonium lactate-acetic acid method - and the 0.01 M $CaCl_2$-soluble N, P and K fractions influenced by such agrotechnical factors as crop rotation, irrigation, and fertilization. My aim was to investigate that how the nitrogen, phosphorus and potassium contents of the soil - determined by traditional methods - can characterize the nutrient supply of the growing area with respect to the reserves of the soil and the easily available nutrient element forms. Similarly to this, compared with the traditional methods, what kind of additional information on the nutrient supply of the growing area are provided by the 0.01 M calcium chloride soluble inorganic and organic nitrogen fractions and the amounts of potassium and phosphorus. I consider as of great significance to clarify by nutrient turnover studies, that to what extent are the amounts of directly available and reserve nutrient elements can be characterized by the studied traditional and novel methods. In addition, is there a possibility to apply the traditional and novel soil analysis techniques simultaneously for the precise characterization of the nutrient supply of a growing area?

3. MATERIAL AND METHOD OF THE STUDIES

3.1. Experimental area, soil characteristics

The soil of the experiment is a lowland calcareous chernozem with deep humus layer, formed on loess. The soil of the experimental area is in a good culture state, of medium plasticity (Arany number: 43), classified as loam by soil physical characteristics. The fertile layer is 80-90 cm thick; 40-50 cm of which is homogenously humous. According to the soil analyses conducted at the beginning of the long-term experiment, the N and P supplies of the soil are medium, while its K content is high (humus content = 2.8-3.0%; Total N = 0.14-0.18%; AL-P_2O_5 = 130-200 mg/kg, AL-K_2O = 240-280 mg/kg). The favourable water management properties of the soil of the experimental area are characteristic of those of the chernozem soils. According to Várallyai it is classified into water management category IV with good hydraulic conductivity and water-bearing ability. The ground-water is located between 6 and 8 meter.

3.2. Experimental settings and design

The long-term experiment set by László Ruzsányi on the Látókép Experimental Farm in 1983 allows the investigation of the effects of crop rotation, irrigation and nutrient supply - as determinant crop production technological elements - and their interactions on the yield results.

During the experiment, three types of crop rotation (maize monoculture; wheat-maize biculture; pea-wheat-maize triculture) were set at five nutrient supply and three irrigation (without irrigation, half and full dose of irrigation) levels, with different tiller numbers (40, 60, and 80 thousand). The size of an experimental plot is 46 m^2.

Table 1. **Fertilizer treatments of the long-term experiment**

Crop rotation	Applied active agent amounts during the maize periods of the maize mono- and bi-cultures			Applied active agent amounts during the wheat and pea periods of the bi- and tri-cultures		
Treatments	N [kg/ha]	P_2O_5 [kg/ha]	K_2O [kg/ha]	N [kg/ha]	P_2O_5 [kg/ha]	K_2O [kg/ha]
1.	0	0	0	0	0	0
2.	60	45	45	50	30	25
3.	120	90	90	100	60	50
4.	180	135	135	150	90	75
5.	240	180	180	200	120	105

3.3. The agrotechnique applied during the long-term experiment

In the maize monoculture, the stubble cleaning was carried out right after harvest. The whole amounts of the P and K fertilizers and the 50% of the N dose were applied before the autumn ploughing; while the remaining part of the N manually in spring, before the making of the seedbeds. The incorporation of the fertilizers applied in autumn was carried out by mounted rotary harrow, flowed by the autumn deep ploughing in 32 cm depth. In spring, the soil works were finished with the tillage and seedbed making. The sowing-time of the Reseda (PR37M81) hybrid maize was around the 20th of April every year. The plant protection treatments in the rotations were uniform, except of the necessary soil disinfection carried out in the monoculture. The clearing of the weeds shooting later was done by mechanical inter-row cultivation. In the irrigation treatments, the amount of irrigation water used during one irrigation rotation was 50 mm, applied in two parts to decrease irrigation loss. The time-point of the irrigation was determined by the cumulated water scarcity values and the symptoms of acute water scarcity caused by the extremely dry hot days. The irrigation was carried out by linear, rain-like irrigation. Among the years of my studies, the irrigation rotations in 2004 were between 8 and 11 June and 6-11 July, while during the extremely moist year of 2005, no irrigation was carried out.

3.4. Characterization of the cropyears of the studied period

The weather and precipitation conditions determining the cropyear of 2004:

The October of the year 2003 was moist (90.0 mm) significantly contributing to the filling up of the decreased ground-water supply after the dry summer. The precipitation in November was 21.7 while that of December was 20.8 mm, both below the multi-year average of 45.2 and 43.5 mm, respectively. Although the precipitation fell in January (37.2 mm) and February (41.6 mm) of 2004 slightly exceeded the multi-year average of 37.0 and 30.2 mm, respectively. The cool weather and the above-the-average precipitation amount in March contributed to the increase of the water supply stored in the soil. In May 2004, both the temperature and the amount of precipitation were below the average, thus the development of maize was slower. From June to the end of September both the temperature and precipitation conditions favoured the development of maize, thus extreme yields were produced in the case of each treatment.

The weather and precipitation conditions determining the cropyear of 2005:

During the autumn of 2004, in October and November the precipitation amounts were above the multi-year average (30.8 mm and 45.2 mm, respectively). In December (33.7 mm) and January (18.2 mm) the precipitation amounts were below the multi-year average of 43.5 and 37.0 mm, respectively. February was characterized by higher-than-average precipitation (40.6 mm, multi-year average: 30.2 mm) and colder-than-average weather. The March of 2005 was extremely dry with only 10.5 mm of precipitation, far below the multi-year average (33.5 mm). In both April and May the precipitation amounts were high (74.9 mm and 75.8 mm, respectively), significantly above the multi-year average; and the temperature conditions were also favourable for the maize. Although the precipitation in June (54.3 mm) was below the multi-year average of 79.5 mm, due to the previous moist period, the water amount available for the rapidly growing and developing maize population was abundant. In July and August the precipitation amounts were also high (99.7 mm and 135.7 mm, respectively), accompanied by favourable temperature conditions for the maize. Due to the cropyear of 2005, the yield amount of maize exceeded even that of the year 2004, which was also considered as very good.

3.5. Samples of the research

During both years, the samples of the research were the plots with 60 thousand stools of the maize monoculture and of the maize period of the winter wheat-maize biculture. Sampling of plant and soil samples were taken according to the treatments summarized in Table 2.

Table 2. **Origin off soil and plant samples according to the treatments**

Crop rotation	**maize monoculture**		**wheat-maize biculture**	
Fertilization P: P_2O_5 kg/ha, K: K_2O kg/ha	**Without irrigation**	**Irrigation with full dose**	**Without irrigation**	**Irrigation with full dose**
N:P:K [kg/ha]	**0:0:0**	**0:0:0**	**0:0:0**	**0:0:0**
N:P:K [kg/ha]	**120:90:90**	**120:90:90**	**120:90:90**	**120:90:90**
N:P:K [kg/ha]	**240:180:180**	**240:180:180**	**240:180:180**	**240:180:180**
Times of sampling in 2004: 29 June; 22 July; 7 September; 4 October				
Times of sampling in 2005: 5 June; 30 June; 30 August; 6 October				

The soil sampling from the experimental plots was carried out with point sampling from the layer of 0 to 200 cm. Every 20 cm was divided from each other from the sampling tube of the boring-machine. The treatments were set in four replicates thus a treatment is characterized by the results of four point soil sampling reducing the errors caused by the point sampling.

In the case of the plant studies, three maize plants per plot were cut in one sampling occasion. The maize plant was divided for parts according to developmental stages (leaf, stalk, spathe, kernel) and the chemical composition of the different parts were determined apart from each other.

3.6. Methods of the laboratory analyses

The 0.01 M $CaCl_2$-soluble organic and inorganic nitrogen fractions and the amounts of potassium and phosphorus were determined according to Houba *et al.* (1986). The total (UV digested), the nitrate and the ammonium nitrogen contents of the samples were measured photometrically by SKALAR segmented continuous flow (SCF) system. The ammonium lactate-acetic acid (AL), phosphorus and potassium contents of the soil samples were determined according to the Hungarian Standard (MSZ 20135:1999).

The nitrogen contents of the plant samples were determined by the Dumas (1831) method with Elementar Vario EL element analyzer.

3.7. Balance calculation procedure

The *simplified agronomic balance* is calculated from the difference of the nutrient fertilizer application rate and the amount of nutrients uptaken by the yield per hectare, without taking into account the losses. The amount of the NPK uptaken by the yield is calculated by multiplying the yield with the specific NPK content of the yield.

The *potential balance* only differs from the simplified agronomic balance in its revenue side. On the potential revenue side of the balance the amount of nutrients that is potentially supplied by the soil is also added to the fertilizer application rate. The amount of NPK uptaken by the plants of control treatment is considered as the potential nutrient supply capacity of the soil. (The nutrient supply capacity of the habitat was characterized by the nutrients amount uptaken by the plants of the unfertilized control treatment).

3.8. Statistical methods

Statistical analysis was performed using SPSS 13.0 software. To reveal relationships between the agronomic factors - treatments, crop rotation, irrigation – and the results of the soil and plant tests correlation analysis and variance analysis were performed. Duncan's post-hoc analysis was performed to detect significant differences between variables relating to different fertilizer rates.

4. RESULTS

4.1. Evaluation of the yield results

The yield results of the long-term experiment (2004 and 2005) and the yield averages of the period of 1994-2005 are summarized in Table 3.

Table 3. **The maize yield amounts in the case of the different treatments**

Maize yield results, without irrigation [t/ha]						
Mode of crop rotation	**Monoculture**			**Biculture**		
N:P_2O5:K_2O treatment [kg/ha]	**0:0:0**	**120:90:90**	**240:180:180**	**0:0:0**	**120:90:90**	**240:180:180**
Yield results, 2004	**7.14^{a}**	**12.73^{b}**	**13.39^{b}**	**9.7^{a}**	**12.8^{b}**	**13.4^{b}**
Yield increase, 2004	**-**	**5.59**	**0.66**	**-**	**3.1**	**0.6**
Yield results, 2005	**8.4^{a}**	**12.3^{b}**	**13.7^{c}**	**11.0^{a}**	**13.0^{b}**	**12.5^{b}**
Yield increase, 2005	**-**	**3.9**	**1.4**	**-**	**2.0**	**-0.5**
Yield average, 1994-2005	**6.1**	**9.0**	**9.2**	**9.1**	**10.4**	**9.9**
Maize yield results, with irrigation [t/ha]						
Mode of crop rotation	**Monoculture**			**Biculture**		
N:P_2O5:K_2O treatment [kg/ha]	**0:0:0**	**120:90:90**	**240:180:180**	**0:0:0**	**120:90:90**	**240:180:180**
Yield results, 2004	**7.2^{a}**	**13.5^{b}**	**14.3^{b}**	**11.7^{a}**	**13.3^{b}**	**13.3^{b}**
Yield increase, 2004	**-**	**6.3**	**0.8**	**-**	**1.6**	**0.0**
Yield results, 2005	**7.6^{a}**	**11.7^{b}**	**13.2^{c}**	**11.1^{a}**	**12.8^{b}**	**12.1^{b}**
Yield increase, 2005	**-**	**4.1**	**1.5**	**-**	**1.7**	**-0.7**
Yield average, 1994-2005	**6.6**	**10.0**	**10.6**	**10.2**	**11.6**	**11.6**

Averages marked with the same letter do not differ from each other at the significance level of p=5%.

In the year 2004, significant yield excesses were produced in the maize monoculture as an effect of the $N_{120}P_{90}K_{90}$ treatment, the amount of yield significantly increased compared to the control, at both water supply levels. Although, as an effect of the $N_{240}P_{180}K_{180}$ treatment, the yield amount further increased, but on one hand, the increase was insignificant and slight thus the consumption of this much fertilizer was causeless on the lowland calcareous chernozem soil. The yield increasing effect of irrigation was only a slight one (6-7%) due to the favourable cropyear with a good amount of precipitation. During the extremely moist 2005, no irrigation was carried out. In this year, the highest yield excess was due to the $N_{120}P_{90}K_{90}$ treatment, while due to the N_{240}:P_{90}:K_{90} treatment, further slight increase was detected.

In the control treatments of the wheat-maize biculture, in 2004, yield was produced to a much greater extent at both irrigation levels than in the monoculture. As a consequence of the increasing fertilizer doses, the yield amount increased without irrigation, but the extent of the increase was below that of the monoculture beside the originally high yield amounts of the control. Significant yield amount increase was experienced only in the case of the $N_{120}P_{90}K_{90}$ treatment. Beside irrigation, also the $N_{120}P_{90}K_{90}$ fertilizer increased the yield amount significantly, while in the case of the $N_{240}P_{180}K_{180}$ treatments, yield decrease to an unreliable extent was observed. In the biculture, as a result of the irrigation, only the yield amount produced in the case of the control decreased to a certifiable extent, compared to the non-irrigated treatments. In the case of the year of 2005, identical statements can be taken with respect to the produced yield amounts and yield excesses as of the previous year.

4.2. Summary of the results of the 0.01 M calcium chloride soluble N-fractions

The results of the studied two years of the long-term experiment confirmed that the fertilization, the crop rotation and the irrigation make significant effects on the nitrogen supply and nitrogen providing of the growing area. The effects of the agrotechnical factors were sensitively reflected by the amounts of the 0.01 M calcium chloride soluble nitrogen fractions in the case of the different treatments. As a result of the increasing doses of nitrogen fertilizers, the calcium chloride soluble nitrogen content of the 0-200 cm soil profile significantly increased in both crop rotations and at both irrigation levels (Table 4). The simplified agronomical balances do not confirm the accumulated nitrate amounts caused by the treatments. The potential balance considering the nutrient element supply of the control soil as nutrient input, therefore confirms the extent of nitrogen accumulation in the studied layer (Table 5). The potential balance and the analysis of the nutrient content of the soil reflect that to what extent the nutrient providing ability of the soil of the growing area contribute to the nutrient element supply of the cultivated crop.

Table 4. **The 0.01 M $CaCl_2$-soluble NO_3-N content of the 0-200 cm soil profile in the average of the four sampling time**

0.01 M $CaCl_2$-soluble NO_3-N content [kg/ha] in 2004						
Mode of crop rotation	**Monoculture**			**Biculture**		
N treatment [kg/ha]	**0**	**120**	**240**	**0**	**120**	**240**
without irrigation	**46.6^a**	**247.4^a**	**941.0^b**	**43.9^a**	**405.2^b**	**1576.2^c**
with irrigation	**40.4^a**	**60.4^a**	**397.0^b**	**76.6^a**	**137.9^a**	**449.3^b**
0.01 M $CaCl_2$-soluble NO_3-N content [kg/ha] in 2005						
Mode of crop rotation	**Monoculture**			**Biculture**		
N treatment [kg/ha]	**0**	**120**	**240**	**0**	**120**	**240**
without irrigation	**104.0^a**	**179.6^a**	**477.3^b**	**146.3^a**	**264.1^a**	**473.2^b**
with irrigation	**99.7^a**	**184.1^a**	**309.9^b**	**171.6^a**	**301.5^a**	**586.2^b**

Averages marked with the same letter do not differ from each other at the significance level of $p=5\%$.

Table 5. **Nitrogen balances in 2004 and 2005 and between 1994 and 2004 in the case of the different treatments**

Nitrogen balances, without irrigation						
Mode of crop rotation	**Monoculture**			**Biculture**		
N treatment [kg/ha]	**0**	**120**	**240**	**0**	**120**	**240**
Simplified agronomical balance, 2004	**-179**	**-198**	**-95**	**-242**	**-199**	**-95**
Potential balance, 2004	**-**	**-20**	**84**	**-**	**43**	**147**
Simplified agronomical balance, 2005	**-210**	**-187**	**-102**	**-275**	**-204**	**-73**
Potential balance, 2005	**-**	**23**	**108**		**71**	**202**
Simplified agronomical balance, 1994-2004	**-1 539**	**-888**	**434**	**-1 704**	**-992**	**283**
Potential balance, 1994-2004	**-**	**651**	**1 973**	**-**	**712**	**1 988**
Nitrogen balances, with irrigation						
Mode of crop rotation	**Monoculture**			**Biculture**		
N treatment [kg/ha]	**0**	**120**	**240**	**0**	**120**	**240**
Simplified agronomical balance, 2004	**-179**	**-218**	**-119**	**-293**	**-212**	**-91**
Potential balance, 2004	**-**	**-39**	**60**	**-**	**82**	**202**
Simplified agronomical balance, 2005	**-190**	**-172**	**-90**	**-278**	**-199**	**-63**
Potential balance, 2005	**-**	**19**	**100**	**-**	**79**	**215**
Simplified agronomical balance, 1994-2004	**-1 835**	**-1 425**	**-238**	**-2 046**	**-1 379**	**-216**
Potential balance, 1994-2004	**-**	**410**	**1 597**	**-**	**667**	**1 830**

In the monoculture, without irrigation, during the optimal cropyear of 2004, even in the case of the 120 kg/ha N treatment a significant, while in the case of the 240 kg/ha N fertilization, highly environmentally risky nitrogen accumulations were observed in the layer of 60-200 cm.

In the biculture, without irrigation, the nitrate amount further increases in the soil of the nitrogen treatments. One cause for the increase is that in the winter wheat period of the biculture the nitrogen uptake is small, thus the non-utilized amount of the fertilizer increases. In addition, a considerable amount of nitrate is formed during the autumn mineralization. The nitrate formed during the autumn mineralization and a part of the non-utilized nitrogen of the fertilizer accumulated under the 100 cm deep layer.

As an effect of the irrigation, in both crop rotations, the amount of nitrate in the studied soil profile significantly decreased mostly due to the washdown and because of the increase of uptake by the plants to a much lesser extent. The deep-seated distribution of the nitrate reflected the effect of irrigation well. Beside irrigation, the accumulation maximum of the nitrate was below 200 cm. During the extremely moist cropyear of 2005, in the non-irrigated nitrogen treatments of the previous year, the nitrate accumulation significantly decreased due to the washdown. The results draw the attention to the fact, that the input material loss can be considerable depending on the applied fertilizer dose, beside irrigation and during a higher-than-average moist cropyear. The nitrate content changes in the 0-200 cm layer due to the N-treatments and irrigation are well demonstrated by the results of the biculture in 2004 (Figure 1).

As an effect of the irrigation and moist cropyear, the conditions of the nutrient recovery improved. In the irrigated control treatments of 2004, the nitrate amount in the 0-200 cm layer did not changed even beside higher yields. In 2005, the nitrate contents of the studied layers were significantly higher in every control treatment than in 2004, albeit record yields were produced on the control plots of both crop rotations. These findings confirm that the calcareous chernozem soil of the Látókép growing area can provide considerable amount of nitrogen under optimal environmental conditions.

In 2004, the effect of crop rotation manifested in two ways. On one hand, the yields of the control plots of the biculture significantly exceeded those of the monoculture, though the calcium chloride soluble nitrate amount in the 0-200 cm layer did not decrease. The main cause of this is that in the biculture a great amount of nitrate was mineralized for the maize of the subsequent year in the growing area, after the winter wheat. The process is confirmed by the significantly higher amount of nitrate at the first sampling time point in the control of the biculture than that of the monoculture. On the other hand, in the case of the 120 and 240 kg/ha nitrogen treatments, the nitrate accumulation was much higher in the biculture than in the monoculture, since during the winter wheat period if the biculture, the nitrogen content of the upper layers are utilized; and the nitrate formed during the autumn mineralization and a part of the non-utilized nitrogen of the fertilizer accumulated under the 100 cm deep layer.

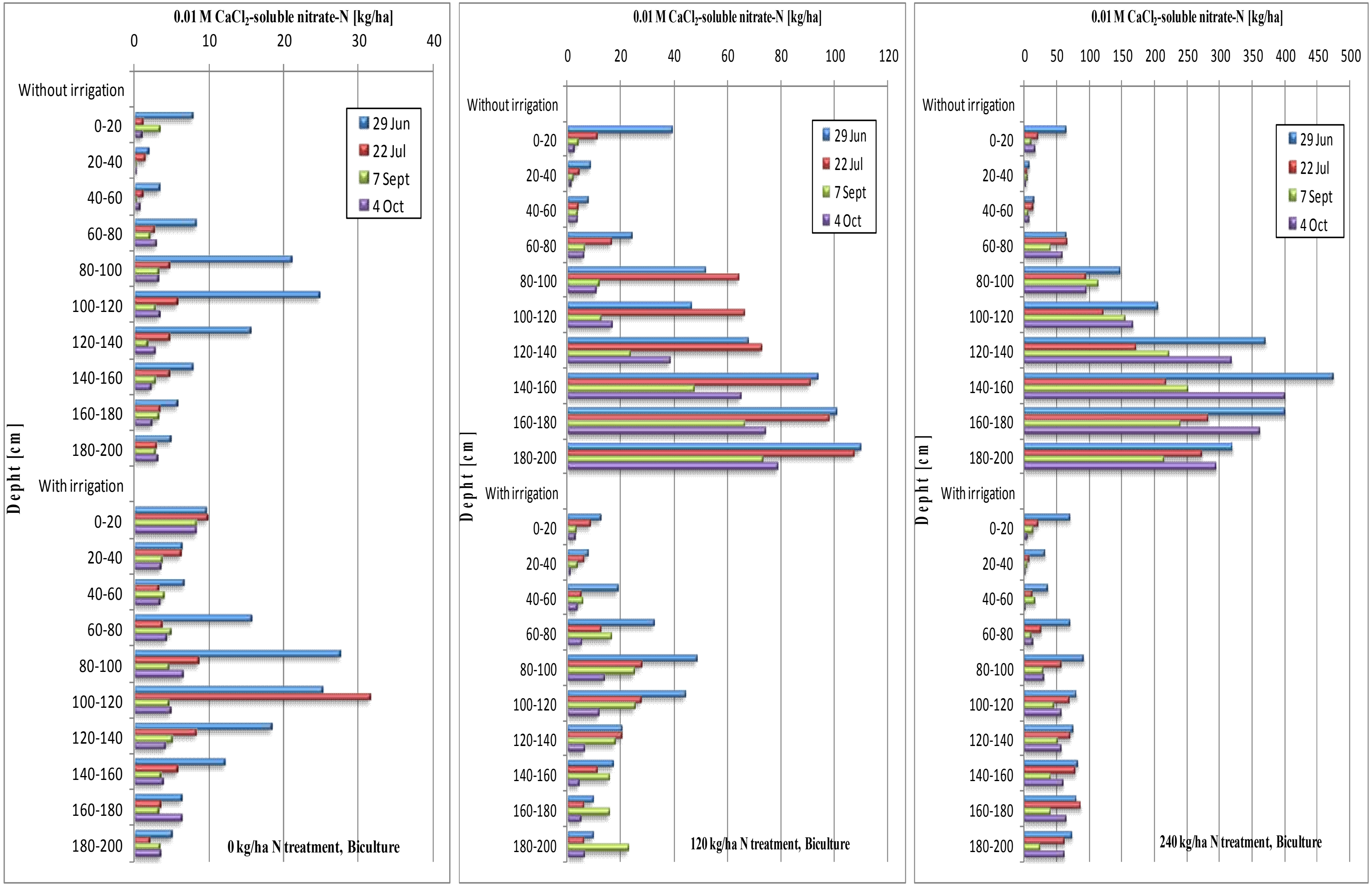

Figure 1: Changes of the amounts of the 0.01 M $CaCl_2$-soluble N-fraction within the soil profile in maize biculture, 2004 year

The 0.01 M $CaCl_2$ soluble and easily oxidisable organic nitrogen fraction of the soil of the long-term experiment is located within the upper 0-60 cm layer of medium humus content; it did not wash down into the deeper layers due to irrigation. Its amount in the growing period changed only in a tight interval within the individual treatments (Table 6). In both crop rotations, the amount of the calcium chloride soluble organic nitrogen fraction increased certifiably, compared to the control, only as an effect of the 240 kg/ha nitrogen fertilization (highest dose). Presumably, the increase was caused by the dissimilation of the organic material remaining from the bigger rootage of the population developed to a greater extent due to the highest fertilizer doses, and in connection, by the increased microbial activity. Beside irrigation, in 2004, the amount of the organic nitrogen fraction in the upper layer certifiably increased at all fertilization levels. The cause of the increase was that as the effect of the irrigation, more favourable environmental conditions formed for the mineralization. In 2005, no irrigation was carried out; there was no difference in the organic nitrogen contents of the upper layers of the irrigated and non-irrigated plots since the environmental conditions determining the mineralization of the organic compounds were identical. The crop rotation had no detectable effect on the amount of the organic nitrogen fraction in neither year. The amounts of the easily soluble and oxidisable organic nitrogen fractions are primarily determined by the nature of the growing area and the conditions of mineralization, therefore the amount of the 0.01 M $CaCl_2$-soluble organic nitrogen fraction is suitable for the characterization of the natural nitrogen supplement of the growing area primarily.

Table 6. **The amounts of the 0.01 M $CaCl_2$-soluble organic nitrogen fraction in the 0-60 cm layer, in the average of four sampling time, during the cropyear of 2004 and 2005**

org.-N content [kg/ha] in 2004						
N treatment [kg/ha]	**Monoculture**			**Biculture**		
	non-irrigated	**irrigated**	**LSD 5%**	**non-irrigated**	**irrigated**	**LSD 5%**
0	**30.3**	**42.0**	**7.4**	**34.7**	**47.0**	**6.2**
120	**31.4**	**48.0**	**6.0**	**38.9**	**42.7**	**4.7**
240	**44.0**	**52.6**	**5.4**	**41.6**	**50.1**	**4.7**
LSD 5%	**11.3**	**5.3**	**LSD 5%**	**4.2**	**9.4**	
org.-N content [kg/ha] in 2005						
N treatment [kg/ha]	**Monoculture**			**Biculture**		
	non-irrigated	**irrigated**	**LSD 5%**	**non-irrigated**	**irrigated**	**LSD 5%**
0	**40.1**	**31.9**	**7.0**	**38.5**	**38.5**	**5.0**
120	**42.6**	**41.8**	**8.7**	**36.2**	**46.4**	**6.8**
240	**50.3**	**47.8**	**10.7**	**41.6**	**60.7**	**19.2**
LSD 5%	**13.5**	**11.3**	**LSD 5%**	**9.2**	**20.1**	

The 0.01 M $CaCl_2$-soluble NH_4-N fraction is located in the 0-60 cm layer in the greatest amount. During the growing period, the NH_4-N content of the upper layer performed fluctuations within a given nitrogen treatment, which is explained by the phenomenon that depending on the circumstances (microbial activity of the soil, moisture content, temperature), the NH_4-N converts quickly. The treatments of increasing dose of nitrogen did not effect the NH_4-N content of the upper layers certifiably. The formation of nitrate from the NH_4-N nitrogen of the applied fertilizer is a quick process. In the studied two years, neither the irrigation, nor the crop rotation made detectable effect on the soluble NH_4-N content of the studied profile. According to the results, the studied agrotechnical factors did not effect the amount of the soluble NH_4-N fraction; in addition, its amount changed extremely depending on the time point of the sampling, thus nor the nitrogen supply or the nitrogen providing ability of the growing area can be characterized by the amount of soluble NH_4-N of the upper layers.

4.2. Summary of the changes in the AL- and $CaCl_2$-soluble P contents

On the calcareous chernozem soil of Látókép, in the growing period of 2004, there were no certifiable effects of the phosphorus treatments of increasing doses, the irrigation and the crop rotation on the calcium chloride soluble phosphorus content of the upper layer. In the growing period of 2005, the 90 kg/ha P_2O_5 treatment, the irrigation and the crop rotation also did not effect the calcium chloride soluble phosphorus content of the upper layer in a certifiable manner. In contrast to the previous year, the calcium chloride soluble phosphorus contents of the upper layers significantly increased compared to the control and 90 kg/ha P_2O_5 treatments, in the case of the P_2O_5 fertilization, both at the different irrigation levels and in the crop rotations. In 2005, the amount of the calcium chloride soluble phosphorus certifiably increased in every treatment combination, compared to the same period of the previous year. The significant increase in the chloride soluble phosphorus contents of the upper layer was due to the cropyear effect. In the extreme moist cropyear of improving solubility conditions, more phosphorus gets into the soil solution. At the phosphorus treatment of the highest dose, it is obvious that a higher amount of phosphorus can get into the soil solution from the accumulated phosphorus supplies, despite the less solubility of the phosphorus compounds (Table 7).

Table 7. **The 0.01 M $CaCl_2$-soluble phosphorus content of the 0-40 cm layer of the soil in the treatments, in the average of four sampling time**

The 0.01 M $CaCl_2$-soluble P_2O_5 content [mg/kg] in 2004						
Mode of crop rotation	**Monoculture**			**Biculture**		
P_2O_5 treatment [kg/ha]	**0**	**90**	**180**	**0**	**90**	**180**
without irrigation	0.9^{a}	1.2^{a}	2.7^{b}	1.5^{a}	1.1^{b}	1.1^{b}
with irrigation	1.0^{a}	1.5^{b}	1.2^{ab}	0.9^{a}	0.8^{a}	1.2^{b}
The 0.01 M $CaCl_2$-soluble P_2O_5 content [mg/kg] in 2005						
Mode of crop rotation	**Monoculture**			**Biculture**		
P_2O_5 treatment [kg/ha]	**0**	**90**	**180**	**0**	**90**	**180**
without irrigation	2.0^{a}	1.7^{a}	3.6^{b}	1.9^{a}	2.3^{b}	2.9^{c}
with irrigation	1.5^{a}	2.3^{b}	4.8^{c}	1.3^{a}	1.7^{b}	3.1^{c}

Averages marked with the same letter do not differ from each other at the significance level of p=5%.

Table 8. **The AL-soluble phosphorus content of the 0-40 cm layer of the soil in the treatments, in the average of four sampling time**

The AL-soluble P_2O_5 content [mg/kg] in 2004						
Mode of crop rotation	**Monoculture**			**Biculture**		
P_2O_5 treatment [kg/ha]	**0**	**90**	**180**	**0**	**90**	**180**
without irrigation	60.2^{a}	120.5^{a}	170.7^{b}	54.9^{a}	83.2^{a}	123.4^{b}
with irrigation	43.2^{a}	96.4^{b}	176.1^{c}	106.2^{a}	111.6^{a}	151.4^{a}
The AL-soluble P_2O_5 content [mg/kg] in 2005						
Mode of crop rotation	**Monoculture**			**Biculture**		
P_2O_5 treatment [kg/ha]	**0**	**90**	**180**	**0**	**90**	**180**
without irrigation	81.7^{a}	143.5^{b}	209.1^{c}	84.2^{a}	85.1^{a}	143.9^{b}
with irrigation	57.9^{a}	107.1^{b}	184.7^{c}	81.3^{a}	81.5^{a}	143.9^{b}

Averages marked with the same letter do not differ from each other at the significance level of p=5%.

Table 9. **Phosphorus balances in 2004 and 2005 and between 1994 and 2004 in the case of the different treatments**

Phosphorus balances, without irrigation						
Mode of crop rotation	**Monoculture**			**Biculture**		
P_2O_5 treatment [kg/ha]	**0**	**90**	**180**	**0**	**90**	**180**
Simplified agronomical balance, 2004	**-93**	**-75**	**6**	**-126**	**-76**	**6**
Potential balance, 2004	**-**	**17**	**99**	**-**	**50**	**132**
Simplified agronomical balance, 2005	**-109**	**-70**	**2**	**-143**	**-79**	**17**
Potential balance, 2005	**-**	**40**	**111**	**-**	**64**	**160**
Simplified agronomical balance, 1994-2004	**-800**	**-158**	**833**	**-839**	**-172**	**746**
Potential balance, 1994-2004	**-**	**642**	**1 633**	**-**	**667**	**1 585**
Phosphorus balances, with irrigation						
Mode of crop rotation	**Monoculture**			**Biculture**		
P_2O_5 treatment [kg/ha]	**0**	**90**	**180**	**0**	**90**	**180**
Simplified agronomical balance, 2004	**-93**	**-86**	**-7**	**-152**	**-82**	**8**
Potential balance, 2004	**-**	**7**	**87**	**-**	**70**	**160**
Simplified agronomical balance, 2005	**-99**	**-62**	**8**	**-144**	**-76**	**23**
Potential balance, 2005	**-**	**37**	**107**	**-**	**68**	**167**
Simplified agronomical balance, 1994-2004	**-954**	**-438**	**483**	**-1 006**	**-366**	**501**
Potential balance, 1994-2004	**-**	**517**	**1 438**	**-**	**640**	**1 507**

In the case of the different treatment combinations, the AL- and calcium chloride soluble phosphorus contents of the upper layers changed very differently. The cause of the difference is due to the characteristics of the extractants and, in connection, the quality of the dissolved phosphorus fractions. The 0.01 M $CaCl_2$ solution is a mild extractant, thus it solubilises the easily dissolvable phosphorus contents, which are directly available for the plants. The phosphorus concentration of the equilibrium extract characterizes the phosphorus amount observed in the soil solution under the given growing area conditions. Otherwise, the 0.01 M $CaCl_2$-soluble phosphorus content can be considered as phosphorus intensity, and thus proportional with the phosphorus amount available from the plant by diffusion under the given circumstances. The culture getting more nutrients from the soil solution and developing more intensely during the growing period takes up more phosphorus accordingly, thus the phosphorus content of the soil solution does not increase proportionally with fertilization, since phosphorus gets slowly into the soil solution. AL is a vigorous extractant. The AL-soluble phosphorus content of the upper layer is significantly higher than the phosphorus amount in the soil solution, since AL can also solubilise a part of the less soluble phosphorus forms that are not available for the plant directly. Thus, the AL-soluble phosphorus content is proportional with the amount of potentially available nutrient supplies determined by the pedological and climatic conditions of the growing area.

4.3. Summary of the changes in the AL- and $CaCl_2$-soluble K contents

Comparing and evaluating the AL- and $CaCl_2$-soluble K contents of the upper layers obtained in the two years of the long-term experiment conducted with different treatment combinations (Tables 10-11), the conclusions are as follows. In both years, due to the potassium fertilization of increasing doses, the AL- and $CaCl_2$-soluble K amounts in the upper layer increased in the case of the maize monoculture. In the monoculture, the AL- and $CaCl_2$-soluble K content of the upper layer was significantly higher beside irrigation than without it, although the potential balance with regard to its cumulated agronomical and control potassium providing were more negative beside irrigation (Table 12). Among irrigation conditions, the clay minerals expanding by moisture allow the potassium replacement on a bigger surface, thus the amount of replaceable potassium increases; and more potassium can get into the soil solution due to the shift of the ion exchange balance.

Table 10. **The 0.01 M CaCl$_2$-soluble potassium content of the 0-40 cm layer of the soil in the treatments, in the average of four sampling time**

The 0.01 M calcium chloride soluble K$_2$O content [mg/kg] in 2004						
Mode of crop rotation	**Monoculture**			**Biculture**		
K$_2$O treatment [kg/ha]	**0**	**90**	**180**	**0**	**90**	**180**
without irrigation	**41.3^{a}**	**55.7^{b}**	**73.7^{c}**	**42.9^{a}**	**48.0^{a}**	**60.9^{b}**
with irrigation	**50.1^{a}**	**73.4^{b}**	**102.5^{c}**	**47.9^{a}**	**51.4^{a}**	**62.0^{b}**
The 0.01 M calcium chloride soluble K$_2$O content [mg/kg] in 2005						
Mode of crop rotation	**Monoculture**			**Biculture**		
K$_2$O treatment [kg/ha]	**0**	**90**	**180**	**0**	**90**	**180**
without irrigation	**46.2^{a}**	**54.6^{b}**	**74.4^{c}**	**54.4^{a}**	**57.0^{a}**	**73.4^{b}**
with irrigation	**55.3^{a}**	**79.7^{b}**	**122.0^{c}**	**61.5^{a}**	**60.7^{a}**	**62.9^{a}**

Averages marked with the same letter do not differ from each other at the significance level of p=5%.

Table 11. **The AL-soluble potassium content of the 0-40 cm layer of the soil in the treatments, in the average of four sampling time**

The AL-soluble K$_2$O content [mg/kg] in 2004						
Mode of crop rotation	**Monoculture**			**Biculture**		
K$_2$O treatment [kg/ha]	**0**	**90**	**180**	**0**	**90**	**180**
without irrigation	**200.1^{a}**	**220.7^{a}**	**273.6^{b}**	**171.5^{a}**	**198.6^{b}**	**231.1^{c}**
with irrigation	**215.5^{a}**	**260.9^{b}**	**306.5^{c}**	**207.5^{a}**	**213.4^{a}**	**237.0^{b}**
The AL-soluble K$_2$O content [mg/kg] in 2005						
Mode of crop rotation	**Monoculture**			**Biculture**		
K$_2$O treatment [kg/ha]	**0**	**90**	**180**	**0**	**90**	**180**
without irrigation	**197.1^{a}**	**212.4^{a}**	**252.6^{b}**	**206.3^{a}**	**209.6^{a}**	**235.6^{b}**
with irrigation	**215.0^{a}**	**263.4^{b}**	**301.2^{c}**	**209.0^{a}**	**215.8^{a}**	**231.5^{b}**

Averages marked with the same letter do not differ from each other at the significance level of p=5%.

Table 12. **Potassium balances in the case of the different treatments**

Potassium balances, without irrigation						
Mode of crop rotation	**Monoculture**			**Biculture**		
K$_2$O treatment [kg/ha]	**0**	**90**	**180**	**0**	**90**	**180**
Simplified agronomical balance, 2004	**-157**	**-190**	**-115**	**-213**	**-191**	**-114**
Potential balance, 2004	**-**	**-33**	**42**	**-**	**22**	**98**
Simplified agronomical balance, 2005	**-185**	**-180**	**-121**	**-242**	**-195**	**-95**
Potential balance, 2005	**-**	**5**	**64**	**-**	**47**	**147**
Simplified agronomical balance, 1994-2004	**-1 354**	**-953**	**39**	**-1 410**	**-838**	**148**
Potential balance, 1994-2004	**-**	**401**	**1 393**	**-**	**572**	**1 558**
Potassium balances, with irrigation						
Mode of crop rotation	**Monoculture**			**Biculture**		
K$_2$O treatment [kg/ha]	**0**	**90**	**180**	**0**	**90**	**180**
Simplified agronomical balance, 2004	**-158**	**-208**	**-136**	**-258**	**-202**	**-112**
Potential balance, 2004	**-**	**-50**	**22**	**-**	**56**	**146**
Simplified agronomical balance, 2005	**-167**	**-167**	**-110**	**-244**	**-191**	**-86**
Potential balance, 2005	**-**	**1**	**57**	**-**	**54**	**158**
Simplified agronomical balance, 1994-2004	**-1 615**	**-1 426**	**-553**	**-1 691**	**-1 166**	**-264**
Potential balance, 1994-2004	**-**	**189**	**1 062**	**-**	**525**	**1 427**

As an effect of irrigation, the lower layers get wet, thus the maize is able to take up a considerable amount of potassium from the deeper layers, and therefore the amount of the non-utilizable fertilizer increases in the upper layer. In the case of the biculture, there was no detectable difference between the the AL- and $CaCl_2$-soluble contents of the upper layers in the plots of the control and 90 kg/ha K_2O treatments. In the winter wheat periods of the biculture, primarily the potassium supply of the upper layers are utilized, while the maize can take up a considerable amount of potassium even from the lower layers with its deep penetrating rootage. Therefore, in monoculture the AL- and $CaCl_2$-soluble potassium contents of the upper layer decrease only to a lesser extent.

These results draw the attention on the fact that the crop rotations utilize the applied fertilizers in a different manner depending on the growing area conditions. On the calcareous chernozem soil of Látókép, the 90 kg/ha K_2O treatment, in the case of the yield amounts produced in the long-term experiment, exceeded the potassium demand of the maize cultivated in the monoculture, thus the AL-soluble K content increased in the upper layer. In the biculture, the 90 kg/ha K_2O treatment can be considered as optimal; the amount of the AL-soluble potassium did not increase compared to the control. In the biculture, the 180 kg/ha K_2O fertilization significantly increased the AL- and $CaCl_2$-soluble potassium contents of the upper layer, at both irrigation levels. Considering the amounts of $CaCl_2$-K and AL-K measured in the case of the control as 100%, as an effect of the increasing treatments the $CaCl_2$-soluble potassium content of the soil increased to a relatively greater extent than the AL-soluble potassium content. Compared to the control, in absolute terms, as an effect of the treatments, the AL-K content increases to a greater extent than the $CaCl_2$-soluble potassium content. This suggest that as an effect of the potassium fertilization, the potassium content of the soil increases - the amount of the AL-soluble potassium also increases -, but it is obvious that the whole amount of the applied fertilizer will not be found in the soil solution, a part is available as a reserve in bound form. Thus, a part of the potassium appearing in the AL extract is deriving from reserves not directly available for the plant. The higher relative increase of the $CaCl_2$-soluble potassium amount confirms that the calcium chloride method sensitively indicated the effects of potassium treatments on the easily replaceable and soluble potassium contents of the soil. The $CaCl_2$-soluble potassium content of the upper layer characterizes the potassium fraction easily available for the plant. As a whole, the potassium amounts soluble in the two different extractants have different information for the evaluation of the potassium supply and potassium providing ability of the growing area. The calcium chloride method sensitively indicated the effects of the potassium treatments on the easily replaceable and soluble potassium contents of the soil, thus gives information on the potassium providing ability of the growing area and the amount of potassium easily available for the plant; while the extent of the potential reserves not directly available for the plant can be characterized by the AL method. With respect to plant nutrition, it is not enough to know the amount of the potentially mobilizable reserves, but the potassium concentration of the equilibrium soil solution, depending on the conditions of the growing area and the quantity and quality of the reserve is of great importance. The traditional AL and the calcium chloride methods can characterize the potassium supply and potassium providing of the growing area in an exact way, complementing each other.

5. NEW AND NOVEL SCIENTIFIC RESULTS

1. My results prove the fact that due to the excellent natural nitrogen supply capacity of the calcareous chernozem soil of the Hajdúság Loess Ridge, the application of N doses above 120 kg/ha is unnecessary in wheat-maize bicultures since the utilization and yield increasing effect of the applied nitrogen fertilizer decrease and significant nitrate accumulation and leaching can occur in the soil profile, especially under irrigated circumstances.

2. I demonstrated that the amount of readily soluble and oxidizable fraction is determined by the characteristics of habitats and by the conditions of mineralization primarily, thus the amount of 0.01 M $CaCl_2$ soluble organic N fraction is suitable for the characterization of the habitat natural N supply ability.

3. On the basis of 0.01 M $CaCl_2$ soluble inorganic and organic soil fractions, the N-requirement can be estimated more accurately, thus environmentally friendly N portions can also be determined.

4. It has been proved that the 0.01 M $CaCl_2$ method indicates the effect of K-treatments more sensitively than the traditional AL- method.

5. Complementing the traditional ammonium lactate-acetic acid (AL) method with the calcium chloride method the potassium and phosphorous supply of the habitat can be characterized in a more precise way.

6. RESULTS APPLICABLE IN PRACTICE

1. Due to the excellent natural nitrogen providing ability of the calcareous chernozem soil of the Hajdúság Loess Ridge, the application of N doses above 120 kg/ha is unnecessary in wheat-maize bicultures in case of Reseda (PR37M81) hibrids and other similar hibrids. The higher doses are utilized poorly and they have significant environmental risk. They can be leached into lower layers of the soil profile and the groundwater, especially under irrigated conditions.

   The determination of the 0.01 M $CaCl_2$-soluble nitrate and organic fractions can be recommended for the characterization of the soil nitrogen supply. The easily mobilizable N reserves of the organic fraction should be considered by the determination of the N dose.

2. The phosphorus supply ability of the studied calcareous chernozem soil is good. The P_2O_5 dose of 90 kg/ha applied for Reseda (PR37M81) maize hibrid in the biculture can be considered as optimal, while in monoculture it is considerably greater than the phosphorus demand of the cultivated culture.

3. In maize monoculture, on calcareous chernozem soils that are similar to the studied habitat, the 90 kg/ha K_2O dose exceeds the demand of the cultivated crop. In biculture, the K_2O dose of 90 kg/ha can be considered as optimal, but the application of higher amounts of fertilizer is unnecessary.

4. To determine the potassium and phosphorus supply of the soil the application of AL method together with calcium-chloride method can be recommended.

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1. Peter Pepó, Attila Vad, **Sándor Berényi**. (2006): Effect of some agrotechnical elements on the yield of maize on chernozem soil. Cereal Research Communications. **34.1.** 621-624. (IF: 1.037)
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5. Bertáné Szabó Emese, **Berényi Sándor**, Loch Jakab. (2009): A 0,01 M $CaCl_2$, a Baker–Amacher és az ammónium-laktát-ecetsav (AL) kivonószerekben oldható K-tartalom összehasonlítása. Agrokémia és Talajtan. **58.1.** 45-56.
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