The European Journal of Plant Science and Biotechnology ©2010 Global Science Books

Soil Nutrient Content in Buckwheat Production

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ABSTRACT

Nutrient content of soil was measured using a traditional method (Hungarian Standard Msz-08 0206) and after 0.01 M $CaCl_2$ extraction. Better knowledge of 0.01 M $CaCl_2$ extractable nutrients may help to improve the efficient use of fertilizers and organic manure. The amount of nitrate nitrogen (NO_3^--N), ammonium nitrogen (NH_4^+-N) and organic nitrogen (organic-N) were measured in plots of buckwheat seed production in Nyíregyháza. The aim of this paper was to present data on the nitrogen supplying capacity of sandy, brown forest soil. We also studied 0.01 M $CaCl_2$ extractable phosphorus, potassium, magnesium nutrients and soil pH. The main objective was to determine the effects of the nutrient supplying capacity of soil on buckwheat yields in organic agriculture. In organic agriculture, nutrient management is based on the self-sufficiency of the farm, on the entire organic matter production cycle and on the decomposition which takes place within the farm making the farm a sustainable biological system. The rate of metabolism and the organic matter cycle are characteristic features of such production. In our experiment, nitrate-nitrogen (NO_3-N) was highly correlated with the buckwheat yield and the utilised 0.01 M $CaCl_2$ extraction method offers useful information for developing environmentally sound, sustainable agriculture.

Keywords: *Fagropyrum esculentum* Moench, 0.01 M $CaCl_2$ extractable nutrients, organic agriculture

INTRODUCTION

Many studies (Schnurer *et al*. 1985; Anderson and Domsch 1989; Ross and Tate 1993; Solaiman *et al.* 2007) reported that soil microbial biomass and microbial activity are closely related to the organic matter (OM) content of a soil. Microbial biomass correlates positively to the amount of OM supplied over a long period of time but it also responds to a single application of OM originating from post-harvest residues or organic manure (Ocio *et al.* 1991; Camargo *et al.* 2004). Németh *et al.* (1988) showed that the organic nitrogen (N) fraction extracted by electro-ultrafiltration (EUF) is a reliable indication of mineralization during the growing season. The organic nitrogen fraction extracted by EUF indicates that the measured organic nitrogen is easily mineralized, available for plant uptake and does not show any strong correlation to soil OM content. According to Dou *et al.* (2000), mineralization and microbial immobilisation of N are related to soil, climatic condition and nutrient amendment. In the case of N fertilization, the rate of OM mineralization increases, resulting in a decrease in the content of easily decomposable OM (Collins *et al.* 1992; Lovell and Jarvis 1998; Schomberg *et al.* 2009). Appel and Mengel (1990) reported a close relationship between N-organic content and N mineralization potential. Gregorich *et al.* (2006) and Sharifi *et al.* (2008) showed that N mineralization potential can be characterized with sufficient accuracy using organic N-fractions. $CaCl_2$-extraction was found to be more appropriate than EUF or the hot water extraction method. Organic fractions extracted by 0.01 M $CaCl_2$ solution were more closely related to N mineralization than the two other inorganic fractions. Similar results were reported by others (Houba *et al.* 1991; Jászberényi *et al.* 1994; Loch and Jászberényi 1997; Nagy *et al.* 2002; Sharifi *et al.* 2007; Burzynska 2008).

According to Groot and Houba (1995), soluble organic-N extracted with a 0.01M $CaCl_2$ solution is an index for the N-mineralization capacity of soils. In their experiment, the organic N fraction extracted by 0.01 M $CaCl_2$ solution highly correlated with the N uptake of ryegrass (Appel and Mengel 1992). The 0.01 M $CaCl_2$ extractable (NH_4^+-N + NO_3^--N) predicts plant-available N in soils with a high inorganic N fraction; thus, 0.01 M $CaCl_2$ extractable (NH_4^+-N + NO_3^--N) might be widely applicable as an index for plant-available N in fertilized soils. Recent studies have showed that soluble organic nitrogen (SON) varied yearly between 8 and 20 kg/ha in course sand and from 15 to 30 kg/ha in sandy loam. The minimum value was measured in winter; the maximum value in summer. Mengel *et al.* (2000) reported 35-45 kg/ha 0.01 M $CaCl_2$ extractable OM. Under continuous arable cropping, Murphy *et al.* (2000) measured 7-18 kg/ha SON in the 0-25 cm soil layer after 8 years of perennial ryegrass (*Lolium perenne*). This accounted for 33-60% of the total soluble N. Even higher SON was measured in a soil profile of 0-90 cm after ploughing up a long-term experiment on grassland. Appel and Mengel (1992), Kulcsár *et al.* (1997) and Lazányi *et al.* (2002) found a correlation between SON and N mineralization in the potato-growing territory of the Nyírség region, and suggested that SON extracted by 0.01 M $CaCl_2$ solution is a reliable indicator of organic N available for mineralization and plant uptake. Murphy *et al.* (2000) reported similar results in loamy sand with KCl-extractable organic-N.

MATERIALS AND METHODS

The objective of the soil analysis was to determine the soil conditions which influence buckwheat production in organic agriculture. Soil samples were taken using a drill at depths of 0-20, 20-40, 40-60 cm at the beginning of flowering in different buckwheat fields between 2004 and 2006. Samples were transported in plastic bags and dried on wooden trays in a well-aired glasshouse. Before grinding, soil samples were cleaned of plant remains and other contamination, and stored in paper bags in a dry place until examination. Sampling places were marked and buckwheat was harvested on a 2 m^2 area. Soil pH was determined by mixing soil and water together in a 1: 1 ratio. Fifty grams of air-dried soil passed through a 2 mm screen were placed into a 100 ml beaker, and 50 ml distilled water was added. The soil and water were stirred for 1 h. The pH of the soil solution was determined with a glass electrode and a pH meter. In Hungary, pH value is also measured in a 1 M KCl solution, with an ion selective electrode (GPHR 1400, Greisinger elec-

Received: 28 April, 2009. Accepted: 8 May, 2010.

Original Research Paper

Table 1 Soil parameters of buckwheat production territory (n = 90).

Parameters	0-20 cm		20-40 cm		40-60 cm		0-60 cm	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
pH (H_2O)*	6.2	0.5	6.1	0.5	6.0	0.5	6.1	0.5
pH (KCl)*	5.0	0.8	5.0	0.7	4.8	0.7	4.9	0.7
KA*	29.7	0.8	29.9	0.8	29.6	0.6	29.7	0.7
$CaCO_3$ (%)*	0.1	0.1	0.1		0.3		0.1	0.1
OM (%)*	0.8	0.3	0.9	0.3	0.8	0.3	0.8	0.3
y_1*	8.0	1.8	8.1	1.9	8.2	1.5	8.1	1.7
KCl-NO_3 (mg/kg)	3.1	1.8	4.2	2.6	4.2	3.4	3.8	2.7
AL-P_2O_5 (mg/kg)	168.6	90.7	162.5	87.1	161.1	155.4	164.1	114.1
AL-Mg (mg/kg)	251.5	72.1	256.1	72.0	214.1	60.6	240.6	70.3
AL-K_2O (mg/kg)	53.3	28.3	54.9	28.0	58.4	26.7	55.5	27.4
AL-Na (mg/kg)	23.0	11.7	24.6	13.1	23.6	12.8	23.7	12.4
AL-Zn (mg/kg)	1.8	2.8	1.9	3.6	1.5	2.6	1.7	3.0
AL-Cu (mg/kg)	1.6	1.1	1.6	1.1	1.5	0.8	1.6	1.0
AL-Mn (mg/kg)	92.5	56.2	96.8	57.4	110.1	55.3	99.8	56.2
Clay + silt (%)	11.6	3.1	11.8	3.4	12.0	3.7	11.8	3.4
$CaCl_2$-Mg (mg/kg)	1.9	1.8	3.0	2.5	3.2	3.7	2.7	2.8
$CaCl_2$-K (mg/kg)	2.3	0.7	2.2	0.7	1.6	0.4	2.0	0.7
$CaCl_2$-NO_3-N (mg/kg)	3.6	0.7	3.8	0.9	3.4	0.9	3.6	0.9
$CaCl_2$-NH_4-N (mg/kg)	7.8	2.4	8.9	3.4	8.2	4.5	8.3	3.5
$CaCl_2$-N-org (mg/kg)	2.8	1.5	2.7	1.6	2.2	1.8	2.6	1.6
$CaCl_2$-Total-N (mg/kg)	114.1	32.9	117.8	38.3	95.7	28.9	109.2	34.6
$CaCl_2$-orto-P (mg/kg)	45.6	21.1	50.3	32.9	49.7	20.9	48.5	25.4

tronic GmbH.). Hydrolytic acidity (y_1) was measured according to the Hungarian Standard Msz-08 0206. The prepared soil sample was shaken with 0.5 M calcium acetate, and after 16 h, it was titrated with 0.1 M NaOH in the presence of a phenolphthalein indicator. The sum of total acid saturation gives the exchange capacity in mmol/100 g soil. The result is similar to hydrolytic acidity determined using Kappen method.

Plant nutrients were measured with traditional, standardised methods in an AL solution (of 0.1 M ammonium lactate + 0.4 M acetic acid) and 1 M KCl (NO_3-N). Nitrate and ammonium N concentrations were also measured in 0.01 M $CaCl_2$ extracts for 2 h with a 1: 10 soil: solution ratio (Jászberényi *et al.* 1994). Organic N was determined by measuring the difference between total dissolved N and inorganic N (NO_3^- NH_4^+), as described by Houba *et al.* (1990, 1991). Principal component analysis (PCA) was used to examine the relationships among soil characters and buckwheat yield. Principal components were computed from the correlation matrix of soil parameters and buckwheat yield. We carried out the examinations using the SPSS 13.0 for Windows program package.

RESULTS AND DISCUSSION

The fertility of a soil depends on the amount of easily weatherable minerals and on the direction and speed of the weathering process. When describing the sandy soils of the Nyírség, OM content is of primary importance. Sandy soil is poor in humus, and OM content is below 1%. A significant part of Nyírség was woodland, where forest soil developed. Traces of iron accumulation near the surface can be observed even today. Following its deforestation winds played an important part in the formation of the surface. Rye was a traditional crop on the brown sandy soil of Nyírség. With appropriate nutriment management, good winter wheat yields can be achieved, and even potato, cucumber and tomatoes can be grown successfully. Among legumes, white and yellow lupines are very well-adapted. The most important soil parameters are listed in **Table 1**.

Soil pH

The primary effect of soil pH on plant growth is associated with the chemical environment. The major influence of pH is on nutrient availability, especially in mineral soils (Nagy *et al*. 2002). As a result of microbiological activity, N availability is the highest between pH 6 and 8. The availability of phosphorus (P) is reduced by precipitation and adsorption by an iron and aluminium complex in acidic soil (Houba *et al.* 1990). Buckwheat tolerates soil acidity more than many other crops and can grow successfully on soils with a pH between 5.5 and 6.5. This crop produces reasonably well at pH levels between 5.0 and 6.0 if adequate P is provided. Buckwheat has about the same acid tolerances as oat and potatoes, grows well on acid soils and gives little response to liming above a pH of 5.0 but many crops grown in rotation with buckwheat require liming (Annan and Amberger 1989).

This higher concentrated 1 N KCl salt solution completely displaces hydronium, whereas 0.01 M $CaCl_2$ does not. As a result, the pH measured in 1N KCl solution is lower than pH (water). The numerical difference in pH measured in KCl and H_2O is referred to as the ΔpH or hide acidity which provides an assessment of the nature of the net charge on the colloidal system. In our experiment, there was a strong correlation between pH measured in KCl and H_2O in the soil samples of buckwheat production territory (**Fig. 1**). This strong correlation can be explained by limited variation in clay minerals and OM content.

Nitrogen

The large need of plants for N and the limited ability of soils to supply available N cause N to be the most limiting nutrient for crop production in organic agriculture in the Nyírség region. A lack of N causes buckwheat leaves to yellow. Vegetative growth is rapid and foliage is dark green in colour if the N supply is adequate. In well-drained and moist agricultural soils with a pH of 6.0, higher levels of nitrification occur rapidly in vegetation period and the nitrate is rapidly absorbed by buckwheat roots.

In Hungary, total soluble N is measured in 1 M KCl extract. In the experiment, there was a good correlation between total N measured in 0.01 M $CaCl_2$ extract and NO_3-N measured in 1 M KCl extract (**Fig. 2**). Soils contained more N in their upper 20 cm thick layer than in the underlying layers.

OM is vital to sustainable agriculture and the effective utilisation of crop residues and manures are central to organic farming. It helps to maintain soil structure and water-holding capacity and has a central role in soil fauna and nutrient cycling. Currently, the Hungarian N management system employs an index based on soil parameters and crop management. In our experiment while the 0.01 M $CaCl_2$ extraction method has proved reliable for determining the N supplying capacity of soils, there was no correlation be-

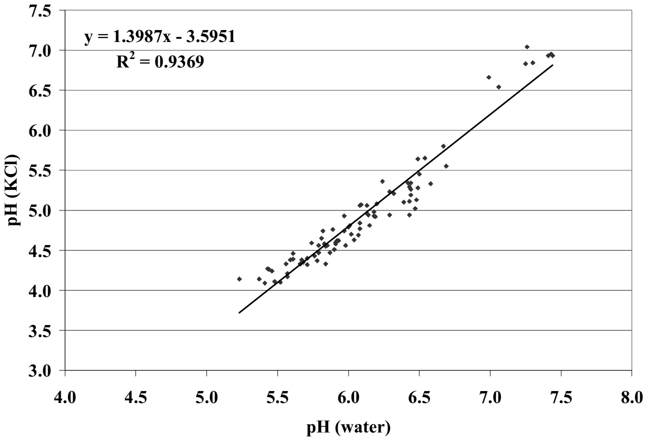

Fig. 1 Relationship between pH (H_2O) and pH (KCl) in the soil of a buckwheat field.

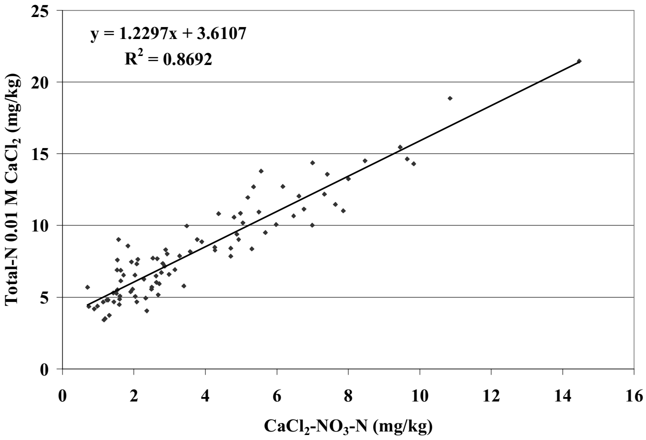

Fig. 2 Relationship between $CaCl_2$ total-N and KCl NO_3-N in the soil of a buckwheat field.

tween the original OM content of the soil and 0.01 M $CaCl_2$ extracted organic N (**Fig. 3**). Organic N measured after 0.01 M $CaCl_2$ extraction indicates the amount of residue which mineralised easily and showed a strong correlation to available N-fractions. The objective of the current study was to evaluate relevant soil management data and the amount of 0.01 M $CaCl_2$ soluble organic-N in the root profile and to predict the effects of organic and inorganic forms of N in buckwheat production. As a result of changes in manure management systems and the decreasing number of animals, farmers in the Nyírség region use limited amounts of organic manure. In an organically managed buckwheat field, the OM content varied between 0.3 and 1.6 %, while 0.01 M $CaCl_2$ soluble organic-N content varied between 2 and 6 mg/kg soil. The N cycle of soils is a part of the larger N cycle. A significant part of soil N occurs in OM and this derives from the biological fixation of N from the atmosphere. Eventually, however, N returns to the atmosphere through a series of processes such as mineralization, nitrification, immobilisation and denitrification (Stark and Richards 2008).

The N content of sandy soil is between 0.02 and 0.12% corresponding to a total amount of 0.5-2.5 t/ha in the upper, cultivated layer (Lazányi 2003). The amount of N available for plants is much less and influenced by many factors, including soil OM content. A large part of the N derives from OM of floral, faunal and microbiological origins. The amount of N mineralised tends to be influenced by soil and environmental conditions. Brown forest soils in the Nyírség region are low in OM and the N supplying capacity was 15.6 kg/ha/year in the fallow treatment of Westsik's crop rotation experiment (Lazányi 2003) where roots and green manure increased the N supplying capacity of soil by more

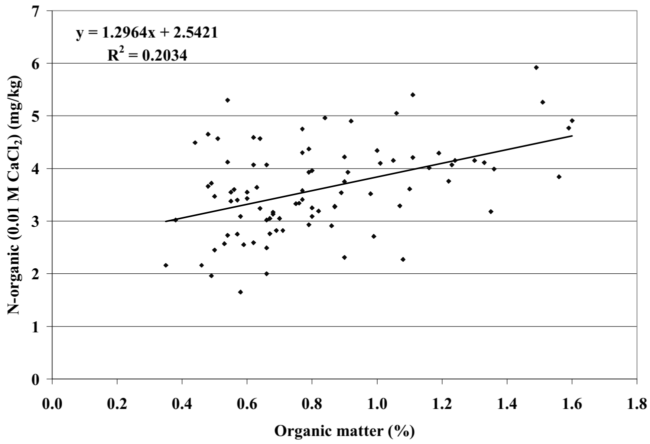

Fig. 3 Relationship between organic matter and organic nitrogen.

than 100%. This increase is caused by lupine which is very well-adapted to the acidic soil conditions of the Nyírség region and is cultivated as a green or root manure crop to increase soil fertilitynds biosynthesis known as condensed tannins.

Phosphorous

Buckwheat shows little response to phosphate content of soil because it also uses insoluble phosphorous (P) sources. Zhu *et al.* (2002) demonstrated that buckwheat has a good ability to take up P, which is released back into the soil in a plant-available form following incorporation of buckwheat residue into the soil (Bowman *et al.* 1998). The roots of buckwheat exude oxalic acid allowing buckwheat to grow well in P-deficient, acidic soils. The mechanism for this resistance is believed to be related to the immobilization and detoxification of aluminium by P in the root tissues (Zhu *et al.* 2002). Additional support for P acquisition and release is provided by Annan and Amberger (1989) who hypothesized that the high activity of acid phosphatase in the rhizosphere contributed to the release of P acquired under low concentrations of soil P. Buckwheat has the capability to use P from organic sources, as well.

The P measured after ammonium-lactate (AL) and 0.01 M $CaCl_2$ extraction may not accurately reflect the amount of P available to buckwheat but the two methods showed a good correlation (**Fig. 4**). Transport of available P from soil to the extraction solution is affected by several factors (Koopmans *et al.* 2005; Nowack *et al.* 2007). The amount of P in the 0.01 M $CaCl_2$ extract is lower than in the AL extraction. The latter dissolves P-forms that are not available for plant uptake at specific soil pH levels. AL extraction method is widely used in Hungary to determine soil P status.

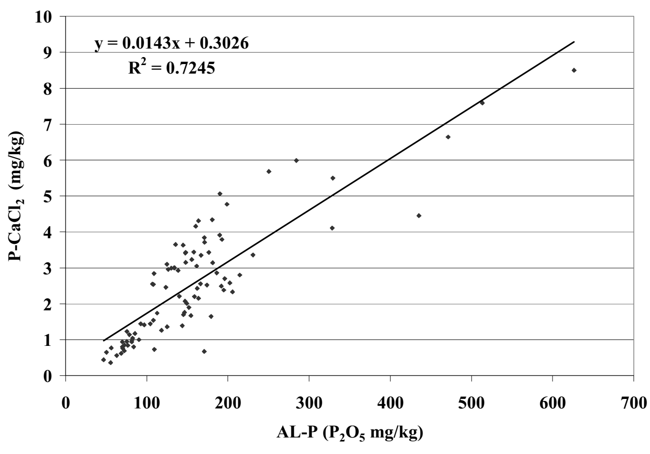

Fig. 4 Relationship between AL-P_2O_5 and 0.01 M $CaCl_2$ extractable P_2O_5.

This analysis of soil samples from buckwheat production sites revealed a significant correlation between AL and 0.01 M $CaCl_2$ extractable P ($R^2 = 0.7245$) and it is recommended to use 0.01 M $CaCl_2$ extraction in organic buckwheat production. On the other hand, it is not expected that buckwheat will respond to additional P at soil tests above 180 mg AL-P_2O_5/kg soil.

Potassium

Studies have also shown that the amount of exchangeable potassium (K) in many soils is about equal to the annual uptake of buckwheat and that the amount in the solution at any given instant is equal to 1 to 3% of the exchangeable K. Assuming that the K in a solution is equal to 2% of the exchangeable K, the soil solution in effect will have to be depleted and replaced about 50 times during the growing season. The K is released and eventually removed from the soil by leaching. Sandy soils also have a low capacity to supply K for plant growth. Many researchers have found that biotite is a good source of K. The relative weathering rates and release of K from microcline, muscovite, and biotite have been reported to be 1.0, 1.8 and 190, respectively. There is also evidence that roots play a role in the removal of K from biotite but plants differ in their capacity to use biotite K. The rapid weathering rate of biotite accounts for its low content in most soils whereas the very slow weathering rate of muscovite accounts for its presence in the clay fraction of most soils. The weathering of feldspar in the sand fraction also contributes to the release of K in some sandy soils.

The K reported in soil tests may not accurately reflect the amount of K available to a buckwheat crop but the two methods showed good correlations (**Fig. 5**). Diffusion of K ions through soil water to roots is the most limiting step in K uptake during the growing season. The results are highly dependent on soil physical characteristics, as well as the forms and amounts of subsoil nutrients. It neither is – nor is it expected – that buckwheat will respond to additional K in soil tests above 200 mg K_2O/kg soil. AL extraction method to determine K requirements is widely used in Hungary. Several investigations in the Nyírség region also have proved the importance of the 0.01 M $CaCl_2$ extraction method and in our experiment we found a strong correlation between the two methods. Similar to P, a part of the soil reserves are in the AL extract and this reserve provides higher amounts of soil K. It is highly recommended to use the 0.01 M $CaCl_2$ extraction method in organic agriculture.

Magnesium

Magnesium (Mg) is an important nutrient for plants. Mg is a component of several primary and secondary minerals in the soil, which are essentially insoluble for agricultural considerations (Loch and Jászberényi 1997), (Lazányi 2003). These materials are the original sources of its soluble or available forms. Mg is also found in ionic form (Mg^{++}) adhered to the soil colloidal complex. The ionic form is considered to be available to crops and sandy soils in the Nyírség region are usually low in Mg even so deficiencies occur only on highly leached soils. Mg availability is related to the cation exchange capacity (CEC) of soil. Low CEC soils hold less Mg and low soil pH decreases its availability. Acid soil can significantly reduce the plant uptake of Mg, and it is in competition with other cations, such as calcium (Ca^{++}) and potassium (K^+). K appears to be a stronger competitor. Mg is very abundant in nature and a large number of minerals contain it, for example dolomite and magnesite. Mg is washed from rocks and subsequently ends up in water.

The Mg content of the acid soils of the Nyírség region is usually low. In the organically managed buckwheat production territory, the amount of 0.01 M $CaCl_2$ extracted Mg varied between 20 and 100 mg/kg soil. AL extracted Mg found in the cultivated layers of soil ranges from 60 to 300 kg/ha. Buckwheat uses 2 kg Mg to produce 1 t of main crop and the by-product and the amount of Mg uptake by plants is 3-5 kg/ha, which represent a negative Mg balance. There was a positive correlation between Mg extracted by 0.01 M $CaCl_2$ procedure and conventional AL method (**Fig. 6**). There was a strong correlation ($R^2 = 0.934$) between AL and 0.01 M $CaCl_2$ extracted soil Mg in our experiment. The value of AL and 0.01 M $CaCl_2$ extracted soil Mg were very close, as a result of the low calcium carbonate content in the soil. In international practice, the 0.01 M $CaCl_2$ extraction method is widely used, although it can not be recommended for soils containing calcium carbonate.

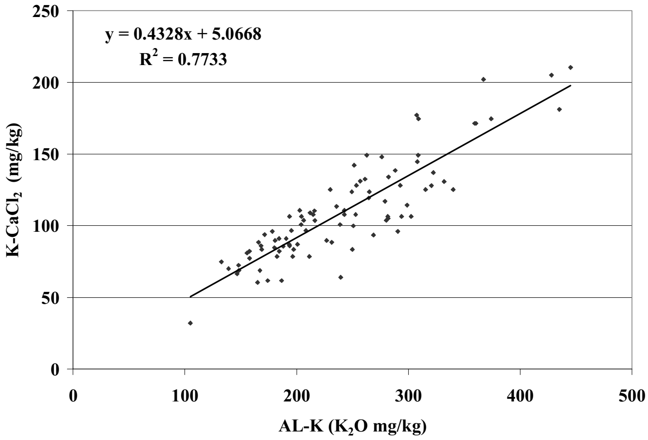

Fig. 5 Relationship between AL-K and K-$CaCl_2$ in soil of buckwheat field.

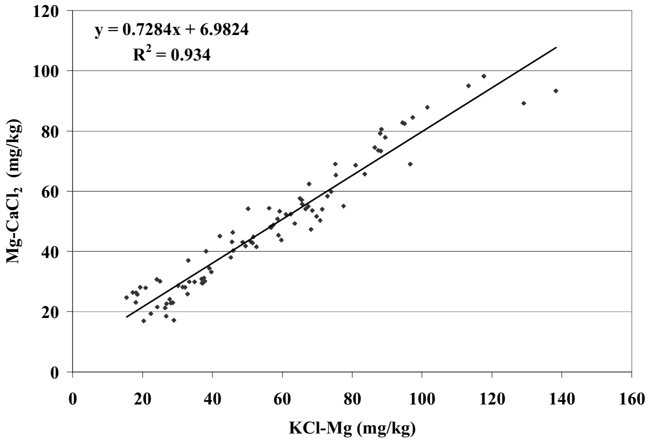

Fig. 6 Relationship between AL-Mg and Mg-$CaCl_2$ in the soil of a buckwheat field.

Results of PCA

In Hungary, fertilizer recommendations are based on crop requirements, soil parameters, the drought index, the supply of N by crop residues, as well as the N and OM contents of the soil (Kulcsár *et al.* 1997). This comprehensive study of buckwheat production allows the use of statistical methods to point out the relationships between soil characteristics and buckwheat yield. Factor analysis can serve as an ideal tool in describing the state of the soil with the introduction of complex variables.

In the second factor, buckwheat yield shows a positive relationship with NO_3-N, N-org and total-N measured in 0.01 M $CaCl_2$ extracts (**Table 2**). PCA has proved the role and the importance of N-forms extracted by 0.01 M $CaCl_2$ in buckwheat production. In the sandy soils of the Nyírség region, buckwheat responds well to nutrients and removes approximately 26 kg of N, 16 kg of P_2O_5, and 48 kg of K_2O from the soil to produce 1 t/ha yields. Too much N increases weed pressure, encourages excessive vegetative growth,

Table 2 Result of principal component analysis. **Bold** = dominant features within principal components.

Components	C-1	C-2	C-3	C-4
Variance (%)	47.52	27.20	7.97	6.39
Buckwheat yield (t/ha)	-0.03	**0.98**	-0.14	0.05
pH (KCl)	**-0.72**	0.02	**0.42**	**0.47**
pH (H_2O)	-0.38	0.37	**0.57**	**0.51**
KA	**0.94**	0.09	0.13	0.10
OM (%)	**0.84**	-0.12	-0.04	0.18
KCl-NO_3 (mg/kg)	-0.01	**0.94**	0.18	-0.05
AL-P_2O_5 (mg/kg)	**0.98**	0.00	0.00	-0.05
AL-Mg (mg/kg)	**0.94**	-0.01	0.13	-0.09
AL-K_2O (mg/kg)	**0.93**	-0.07	-0.11	0.31
AL-Na (mg/kg)	**0.68**	-0.04	**0.48**	-0.35
AL-Zn (mg/kg)	**0.95**	0.10	0.00	0.17
AL-Cu (mg/kg)	**0.99**	0.08	-0.05	0.05
AL-Mn (mg/kg)	**0.98**	0.05	0.02	0.14
Clay + silt (%)	**0.90**	0.25	0.11	-0.09
$CaCl_2$-Mg (mg/kg)	**0.74**	0.44	0.31	-0.05
$CaCl_2$-K (mg/kg)	**0.55**	-0.50	-0.36	0.16
$CaCl_2$-NO_3-N (mg/kg)	0.02	**0.94**	-0.18	0.10
$CaCl_2$-NH_4-N (mg/kg)	0.18	**-0.92**	-0.26	0.14
$CaCl_2$-N-org (mg/kg)	-0.06	**0.61**	**-0.66**	0.21
$CaCl_2$-Total-N (mg/kg)	0.03	**0.92**	-0.25	0.13
$CaCl_2$-orto-P (mg/kg)	-0.07	0.47	-0.06	**-0.63**

causes lodging and decreases grain yield (Kulcsár *et al.* 1997). Excess N responses are especially noticeable when P is deficient. In springtime when buckwheat is growing quickly, N mineralization is rapid in organic agriculture and additional N is unnecessary.

REFERENCES

Anderson T, Domsch KH (1989) Ratios of microbial biomass carbon to total organic carbon in arable soils. *Soil Biological Biochemistry* **21**, 471-479

Annan A, Amberger L (1989) Phosphorus efficiency of buckwheat. *Zeitschift für Pflanzenernährung und Bodenkunde* **152**, 181-189

Appel T, Mengel K (1990) Importance of organic nitrogen fractions in sandy soils, obtained by electro-ultrafiltration or $CaCl_2$ extraction, for nitrogen mineralization and nitrogen uptake of rape. *Biology and Fertility of Soils* **10**, 97-101

Appel T, Mengel K (1992) Nitrogen uptake of cereals grown on sandy soils as related to nitrogen fertilizers application and soil nitrogen fractions obtained by electro-ultrafiltration (EUF) and $CaCl_2$ extraction. *European Journal of Agronomy* **1**, 1-9

Bowman G, Shirley C, Cramer C (1998) Managing cover crops profitably. Sustainable Agriculture Network Handbook Series, Book 3. Available online: http://www.sare.org/

Burzynska I (2008) Application of 0.01 M CaCl2 soil extract to determine macro and micronutrients in the meadow soil and to assess ground water quality. *Water-Environment-Rural Areas* **8/2**, 13-32

Camargo FAO, Gianello C, Tedesco MJ (2004) Soil nitrogen availability evaluated by kinetic mineralization parameters. *Communications in Soil Science and Plant Analysis* **35**, 1293-1307

Collins HP, Rasmussen PE, Douglas CL (1992) Crop rotation and residue management effect on soil carbon and microbial dynamics. *Soil Science Society of America Journal* **56**, 783-788

Dou H, Alva AK, Appel T (2000) An evaluation of plant-available soil nitrogen in selected sandy soils by Electro-Ultrafiltration, KCl, and $CaCl_2$ extraction methods. *Biology and Fertility of Soils* **30**, 328-332

Gregorich EG, Beare MH, McKim UF, Skjemstad JO (2006) Chemical and biological characteristics of physically uncomplex organic matter. *Soil Science Society of America Journal* **70**, 975-985

Groot JJR, Houba VJG (1995) A comparison of different indices for nitrogen mineralisation. *Biology and Fertility of Soils* **19**, 1-9

Houba VJG, Jászberényi I, Loch J (1991) Application of 0.01 M $CaCl_2$ as a single extraction solution for evaluation of the nutritional status of Hungarian soils. *Debreceni Agrártudományi Egyetem Tudományos Közleményei* **30**, 85-89

Houba VJG, Novozamsky I, Lexmond THM, van der Lee JJ (1990) Applicability of 0.01 M $CaCl_2$ as a single extraction solution for the assessment of the nutrient status of soils and other diagnostic purposes. *Communications in Soil Science and Plant Analysis* **21**, 2281-2290

Jászberényi I, Loch J, Sarkadi J (1994) Experiences with 0.01 M calcium chloride as an extraction reagent for use as a soil testing procedure in Hungary. *Communications in Soil Science and Plant Analysis* **25**, 1771-1777

Koopmans GF, Chardon WJ, van der Salm C (2005) Disturbance of water-extractable phosphorus determination by colloidal particles in a heavy clay soil from the Netherlands. *Journal of Environmental Quality* **34**, 1446-1450

Kulcsár L, Debreczeni K, Jászberényi I, Loch J (1997) Investigation of the soil N-fractions in special consideration of the N-fertilizer recommendation for sugar beet. *Poster on the 11th World Fertilizer Congress 7-13. September 1997*. Gent, Belgium

Lazányi J (2003) Results of sustainable production in Westsik's crop rotation experiment. Westsik Vilmos Foundation for Rural Development, Nyíregyháza, pp 1-205

Lazányi J, Loch J, Jászberényi I (2002) Analysis of 0.01 M $CaCl_2$ soluble organic nitrogen in the treatments of Westsik's crop rotation experiment. *Agrokémia és Talajtan* **51/1-2**, 79-89

Loch J, Jászberényi I (1997) The 0.01 M $CaCl_2$ solution as a multi-element soil extractant – application and experiences in Hungary. In: Filep Gy (Ed) *Land Use and Soil Management*, Rexpo Ltd 1997. Debrecen, Hungary, pp 175-184

Lovell RD, Jarvis SC (1998) Soil microbial biomass and activity in soil from different grassland management treatments stored under controlled conditions. *Soil Biology and Biochemistry* **30**, 2077-2085

Mengel K, Schneider B, Kosegarten H (2000) Nitrogen compounds extracted by electro-ultrafiltration (EUF) or $CaCl_2$ solution and their relationships to nitrogen mineralization in soils. *Journal of Plant Nutrition and Soil Science* **162**, 139-148

Murphy DV, MacDonald AJ, Stockdale EA (2000) Soluble organic nitrogen in agricultural soils. *Biology and Fertility of Soils* **30**, 374-387

Nagy PT, Jászberényi I, Loch J (2002) A trágyázás hatása a 0.01 M kalcium-kloridban oldható nitrogénformák mennyiségére a nyírlugosi tartamkísérletben. In: Láng I, Lazányi J, Németh T (Eds) Tartamkísérletek, Tájtermesztés, Vidékfejlesztés Nemzetközi Konferencia I., pp 143-148

Németh K, Bartels H, Vogel M, Mengel K (1988) Organic nitrogen compounds extracted from arable and forest soils by electro-ultrafiltration and recovery rates of amino acids. *Biology and Fertility of Soils* **5**, 537-539

Nowack B, Mayer U, Oswald S, van Beinum W, Appelo C, Jacques D, Seuntjens P, Gerard F, Jaillard B, Schnepf A, Roose T (2007) Verification and intercomparison of reactive transport codes to describe root-uptake. *Plant and Soil* **285**, 305-321

Ocio JA, Martinez J, Brookes PC (1991) Contribution of straw-derived N to total microbial biomass N following incorporation of cereal straw to soil. *Soil Biology and Biochemistry* **23**, 655-659

Ross DJ, Tate KR (1993) Microbial C and N, and respiratory activity in litter and soil of southern beech (*Nothofagus*) forest: distribution and properties. *Soil Biology and Biochemistry* **25**, 477-483

Schnurer J, Clarholm M, Rosswall T (1985) Microbial biomass and activity in agricultural soil with different organic matter contents. *Soil Biology and Biochemistry* **17**, 611-618

Schomberg HH, Wietholter S, Griffin T S, Reeves DW, Cabrera ML, Fisher DS, Endale DM, Novak JM, Balkcom KS, Raper RL, Kitchen NR, Locke MA, Potter KN, Schwartz RC, Truman CC, Tyler DD (2009) Assessing indices for predicting potential nitrogen mineralization in soils under different management systems *Soil Science Society of America Journal* **73**, 1575-1586

Sharifi M, Zebarth BJ, Burton DL, Grant CA, Bittman S, Drury CF, McConkey BG, Ziadi N (2008) Response of potentially mineralizable soil nitrogen and indices of nitrogen availability to tillage system. *Soil Science Society of America Journal* **72**, 1124-1131

Sharifi M, Zebarth BJ, Burton DL, Grant CA, Cooper JM (2007) Evaluation of some indices of potentially mineralizable nitrogen in soil. *Soil Science Society of America Journal* **71**, 1233-1239

Solaiman Z, Marschner P, Wang D, Rengel Z (2007) Growth, P uptake and rhizosphere properties of wheat and canola genotypes in an alkaline soil with low P availability. *Biology and Fertility of Soils* **44**, 143-153

Stark CH, Richards KG (2008) The continuing challenge of agricultural nitrogen loss to the environment in the context of global change and advancing research. *Dynamic Soil, Dynamic Plant* **2**, 1-12

Zhu YG, He YQ, Smith SE, Smith FA (2002) Buckwheat (*Fagopyrum esculentum* Moench) has high capacity to take up phosphorus (P) from calcium (Ca)-bound source. *Plant and Soil* **239**, 1-8