Szent István University

IMPROVEMENTS IN THE NUTRITION OF WINTER BARLEY ON A CHERNOZEM MEADOW SOIL

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1. BACKGROUND AND AIMS

The new challenges raised by the demand for sustainable agriculture will require improvements the components of the fertilisation advisory systems (Németh and Jolánkai 2002, Jolánkai 2003). One important aspect of these improvements will be the analysis of the nutrient-supplying ability of the soil types belonging to various arable land categories, the more precise determination of limit values for nutrient supplies and their calibration in plant experiments (Kádár 1992, Csathó et al. 1998, Várallyay and Németh 1999, Németh et al. 2002, Izsáki 2008).

Very few papers have been published in Hungary on the mineral fertilisation of winter barley, and many of those available have become outdated. The data in the modest number of papers published abroad on this subject are difficult to adapt to Hungarian circumstances due to the very diverse growing conditions. Based on present production conditions and cultivars, Kádár (2000) classified winter barley, like winter wheat, as a crop with a high demand for nitrogen (N). N fertilisation is the most critical component of winter barley nutrition. In general the N supplies of the soil are judged on the basis of humus content when determining the N fertiliser requirements. An important part of the improved N fertiliser recommendations for winter barley is the application of top-dressing, based on the determination of the mineral N content of the soil (N_{min} method), supplemented with diagnostic plant analysis (Elek and Kádár 1980, Németh 2002, Izsáki and Németh 2007). Limit values based on the results of plant analysis were proposed for Hungarian conditions by Kádár (1988, 2002). Another advantage of performing plant analysis to supplement mineral N analysis is that it provides information on the nutrient supply level of the crop, while the calculation of nutrient ratios indicates how balanced the nutrient level is (Németh 2002).

In addition to N, it is also important to determine the soil phosphorus (P) supplies, as the processing of data from long-term field P fertilisation experiments carried out in Hungary revealed that not only legumes and root crops have high P requirements, but cereals too (Csathó 2002). This was confirmed by Kádár (2012), who emphasised that good P supplies can only be ensured if the soil is regularly replenished with P.

Cereals have lower K requirements than hoed crops (Lásztity 1989, Kádár 1992, Csathó 1997). Under Hungarian conditions Kádár (2000a) reported that on calcareous loamy chernozem soil a soil potassium content of 120–140 mg/kg AL-K_2O is sufficient to satisfy the K requirements of winter barley. Kádár (2012) also demonstrated that on heavier than average soils cereals give little response to K fertilisation.

Research on the effects of climate change in Hungary suggests that there is likely to be a rise in temperature and a drop in precipitation levels (Gaál and

Horváth 2006, Bartholy et al. 2007), which could increase the importance of barley production.

1.1. Aims of the research

The research aimed to provide a scientific basis for improvements in the fertilisation recommendations for winter barley

The following topics were investigated:

- The long-term mineral fertilisation experiment was set up in Szarvas evaluation of the effect of 4 levels each of N, P and K fertiliser on the yield, yield components and the characteristics of certain economic values of winter barley.
- Determination of N nutrition status by measuring the chlorophyll content (SPAD index) at the beginning and end of the tillering, satisfactory N supply with SPAD values.
- Determination of the N fertiliser requirements of winter barley in autumn and spring on the basis of soil N_{min} content.
- Determination or corrected limit values of nutrient supply levels for winter barley based on diagnostic plant analysis.
- Improvements in fertilisation recommendations based on plant analysis; practical guidelines for foliar fertilisation.

2. MATERIALS AND METHODS

2.1. The treatments and layout of the experiment

The long-term mineral fertilisation experiment was set up at the Experimental Station of the Faculty of Economic, Agricultural and Health Sciences of Szent István University in Szarvas in 1989.

The long-term fertilisation experiment was set up with three factors (N, P, and K fertilisation) with all combinations of four levels each of N, P and K supplies, giving a total of 64 treatments arranged in a split-split plot design with three replications. Within the three true replications, the N fertiliser treatments were present in 48 internal replications and the P treatments in 16.

Experimental factors and treatments

Factor A (K fertilisation) involved the following treatments:

K_0 = without K fertilisation,

K_1 = 300 kg/ha/year K_2O from 1989–1992, 100 kg/ha/ year from 1993 onwards,

K_2 = 600 kg/ha K_2O in 1989, 1000 kg/ha in 1993 and 600 kg/ha in 2001,

K_3 = 1200 kg/ha K_2O in 1989, 1500 kg/ha in 1993 and 1200 kg/ha in 2001.

Factor B (P fertilisation) involved the following treatments:

P_0 = without P fertilisation,

P_1 = 100 kg/ha year P_2O_5,

P_2 = 500 kg/ha P_2O_5 in 1989, 1993 and 2001,

P_3 = 1000 kg/ha P_2O_5 in 1989, 1993 and 2001.

The aim of the periodic application of high rates of P_2, P_3 and K_2, K_3 fertiliser was to create clearly distinguishable supply levels in the soil in order to investigate different nutritional situations and to determine limiting values for soil nutrient supply levels.

Factor C (N fertilisation) involved the following treatments:

N_0 = without N fertilisation,

N_1 = 80 kg/N ha/year (40 kg/ha basic fertiliser + 40 kg/ ha top-dressing),

N_2 = 160 kg/N ha/ year (80 kg/ha basic fertiliser + 80 kg/ha top-dressing),

N_3 = 240 kg/N/ha/year (120 kg/ha basic fertiliser + 120 kg/ha top-dressing).

The N basic fertiliser and top-dressing was applied in the form of ammonium nitrate (34%), the P as superphosphate (18%) and the K as potassium chloride (40 or 60%). Each year four crops were sown in a full crop rotation on 4 × 192 plots, where the area of the main plots was 320 m², the subplots 80 m² and the sub-subplots 4 × 5 = 20 m². The forecrop of winter barley was canary grass (*Phalaris canariensis L.*) in 2010- and 2011, and soybean (*Glycine max L.*) in 2012. Top-dressing was applied on a single occasion at the end of tillering after plant sampling. The winter barley was harvested at full maturity using a plot combine at the end of June and beginning of July. The experiments were performed on the two-row winter barley cultivar GK Stramm, which was kindly provided by Cereal Research Non-Profit Ltd.

The data processed in this work originated from the 21^{st}–23^{rd} years of the long-term experiment (2010/2011–2012/2013 seasons).

2.2. Soil content

The soil of the experimental station, a chernozem meadow soil calcareous in the deeper layers. had the following parameters: depth of the humus-containing layer 85–100 cm; humus% = 2.8–3.2%; $pH_{(KCl)}$= 5.0–5.2; $CaCO_{3\%}$= 0; upper level of plasticity according to Arany (K_A)= 50; clay content%= 32; and the groundwater level was at an average depth of 300–350 cm. Soil samples were taken each year in autumn from a depth of 0–30 cm for the analysis of soil nutrient contents (K_2O, P_2O_5, NO_3^-- and NO_2^--N) and in spring, prior to top-dressing, from a depth of 0–60 cm to determine the soil mineral N content (NO_3^-- and NH_4^+-N) in the subplots (P_0, P_1, P_2, P_3) and sub-subplots (N_0, N_1, N_2, N_3) of the K_1 main plot. The P_2O_5 and K_2O contents were determined with the ammonium lactate (AL) method, and the NO_3^-- and NO_2^--N contents and mineral N contents (NO_3^-- and NH_4^+-N) from 1 mol/l potassium chloride (KCl) extract using a spectrophotometer. The K and P supplies available in each season were characterised based on the analytical results obtained in the previous autumn.

Table 1. Supply of the soil K, P és N supplies fertilisation levels (Szarvas, 2010-2012 autumn)

Treatment	Years of experimental		
	2010	2011	2012
AL- K_2O in the cultivated layer (0-30 cm) (mg/kg)			
K_0	218	210	212
K_1	324	320	346
K_2	294	335	310
K_3	346	335	348
AL- P_2O_5 in the cultivated layer (0-30 cm) (mg/kg)			
P_0	133	118	124
P_1	206	224	242
P_2	194	186	192
P_3	251	233	244
NO_3^- and NO_2^- -N in the cultivated layer (0-30 cm) (kg/ha)			
N_0	22	46	21
N_1	21	56	60
N_2	20	50	54
N_3	42	52	66

Table 2. The mineral N content of soil (N_{min}) N fertilisation levels in the 0-60 cm soil layer before N top-dressing
(Szarvas, 2011-2013 spring)

Treatment	N-form	N content in the 0-60 cm soil layer (kg/ha)		
		2011	2012	2013
N_0	NO_3^- - N	36	59	28
	NH_4^+-N	66	39	96
	N_{min}	102	98	124
N_1	NO_3^- - N	41	47	76
	NH_4^+-N	79	62	92
	N_{min}	120	109	168
N_2	NO_3^- - N	39	53	58
	NH_4^+-N	77	56	104
	N_{min}	116	108	162
N_3	NO_3^- - N	67	56	78
	NH_4^+-N	91	48	186
	N_{min}	158	104	264

2.3. Weather conditions

In the 2010/2011 season both the precipitation quantity (435 mm) and the mean temperature (8.2°C) exceeded the long-term mean (362 mm, 7.5°C). The driest season was 2011/2012, when there was 135 mm less rainfall than the long-term mean, while the mean temperature during the growing season was 2.9°C higher than the mean for 1901–1975. The precipitation quantity in 2012/2013 was close to the long-term mean, but the distribution was uneven. The mean temperature only deviated slightly from the long-term mean (8.0°C). In this year the large quantity of rainfall at the end of tillering in March (99 mm) prevented samples being taken to determine the nutrient content of winter barley at tillering.

2.4. Technology, sampling methods and analyses applied in the experiment

Measurements of the SPAD index, nutrient content at tillering, straw and ear length, number of grains per ear, thousand-grain weight and test weight of winter barley and the nutrient content of the grain were made on samples from 16 treatments: the subplots (P_0, P_1, P_2, P_3) and sub-subplots (N_0, N_1, N_2, N_3) of the K_1 main plot:

$K_1P_0N_0$	$K_1P_1N_0$	$K_1P_2N_0$	$K_1P_3N_0$
$K_1P_0N_1$	$K_1P_1N_1$	$K_1P_2N_1$	$K_1P_3N_1$
$K_1P_0N_2$	$K_1P_1N_2$	$K_1P_2N_2$	$K_1P_3N_2$
$K_1P_0N_3$	$K_1P_1N_3$	$K_1P_2N_3$	$K_1P_3N_3$

The yield of winter barley was evaluated for all 64 fertiliser treatments.

The first soil samples were taken between September 27th and October 22nd before the application of basic fertilisation (October 10th–22nd). Sowing was carried out with a seed rate of 5 million seeds/ha, at a row distance of 12 cm and a sowing depth of 5 cm on October 14th, November 3rd and October 10th in the three seasons. SPAD values were recorded at the beginning (November 24th–December 3rd) and end (March 3rd–24th) of tillering. Soil samples were then taken before top-dressing (March 31st, March 20th, April 10th) to determine the mineral N content of the 0–60 cm layer. The plant samples were taken from two 1-metre row sections from each plot to determine nutrient contents at tillering (Feekes scale 4–5). In two seasons (spring 2011 and 2012) the following elements were analysed in dried, ground samples of the whole aboveground organs: N, P, K, Na, Ca, Mg, Mn, Zn, Cu, B and Mo and the results were given in terms of dry matter.

We were taken from two 1-metre row sections from each plot to determine the straw length was measured without the ear, while the ear length was measured to the tip of the ear. The thousand-grain weight was determined using a Pfeuffer Contador seed counter, and the test weight on a ¼-litre cereal quality balance.

2.5. Statistical analysis

The nutrient concentration at tillering, the mineral content of the grain yield and the nutrient ratios were evaluated using one-way analysis of variance (ANOVA) with the help of the IBM SPSS program, ver. 20.

This program was also used for two-way ANOVA on the SPAD index, straw and ear length, yield components and test weight and for three-way ANOVA on the yield.

Statistical analysis was performed by means of analysis of variance followed by t-test. To prove the differences between the averages of treatments we applied the least significant difference method (LSD) at 5% probability level, with F-test.

The correlation between the SPAD index and the yield was evaluated using the regression analysis method outlined by Sváb (1981).

3. RESULTS

3.1. Effect of N and P fertilisation on SPAD values of winter barley at the beginning and end of tillering

The chlorophyll contents measured in autumn 2010–2012 showed that a SPAD index of 39–47 represented a satisfactory N nutrition level, which could be achieved with 40 kg/ha N basic fertilisation (N_1) on chernozem meadow soil with good N-supplying ability. No significant increase in the SPAD index was recorded at higher rates of basic N fertilisation (39.1–47.5).

In all three seasons the highest SPAD values (37.7–47.9) were generally recorded after the application of 100 kg/ha/year P fertiliser (P_1), when the soil AL-P_2O_5 content was 206–242 mg/kg. In most cases the P_2 and P_3 treatments led to a decline in the chlorophyll content of winter barley compared to the maximum SPAD index (37.1–47.0), but no significant P effect could be detected in any of the years in the relative chlorophyll content of winter barley leaves at the beginning of tillering over a soil AL-P_2O_5 range of 118–251 mg/kg.

Without N fertilisation (N_0) the N_{min} reserves in the 0–60 cm soil layer at the end of tillering in early spring was 98–124 kg/ha, averaged over the three seasons. In the 40 kg/ha basic N fertiliser (N_1), when the N_{min} content of the soil was 109–168 kg/ha, there was a considerable rise in the relative chlorophyll content of winter barley, with an average SPAD index of 46.4 over the three seasons. The application of 80 kg/ha N basic fertiliser (N_2) caused a slight but significant rise in the SPAD index (43.2–52.1). Excessive N supplies (120 kg N/ha, N_3) had little influence on the relative chlorophyll content of the leaves (43.4–52.8).

Over a soil AL-P_2O_5 range of 118–251 mg/kg in the ploughed layer, P supplies had no significant influence on the relative chlorophyll content of winter barley leaves in the tillering phase (40.7–51.0).

3.2. Effect of N and P supplies on the nutrient concentrations of winter barley at the end of tillering

The highest concentrations of both macro- and micronutrients were generally found in the N_3 treatment (240 kg N/ha), but in all three seasons the maximum yield was obtained with 160 kg N/ha (N_2).

Over a soil AL-P_2O_5 range of 118–251 mg/kg, the effect of the increasing P-supplying ability of the soil on the nutrient content of winter barley at tillering was only significant for the P concentration in the 2010/2011 season, while in the 2011/2012 season there was a significant rise in the concentration of N, P, K, Ca, Mg, Cu and B.

N fertilisation did not significantly affect the nutrient ratios at tillering, but the AL-P_2O_5 supplies of the ploughed layer (118–251 mg/kg) had a significant influence on the N/Ca, N/Mg, N/Cu and P/Zn ratios of winter barley at tillering.

3.3. Effect of N and P supplies on the yield characteristics of winter barley

The results obtained in the 2011–2013 seasons showed that without N treatment (N_0), when the N_{min} content of the soil in spring was 98–124 kg/ha, the straw length of winter barley was 38.1–55.3 cm. In general an improvement in N supplies (N_1, N_2) led to an increase in straw length up to the N_3 treatment, where the mineral N content of the soil was 158, 104 and 264 kg/ha, respectively. In the seasons tested (2011–2013) the naturally occurring AL-P_2O_5 supplies in the ploughed layer (118–133 mg/kg) was sufficient for the achievement of satisfactory straw length. An enhancement of the AL-P_2O_5 content either had no substantial effect on the straw length, or significantly reduced it.

Averaged over the 2011–2013 seasons the shortest ear length (6.1 cm) was measured in plots with no N fertiliser (N_0), where the mineral N content in the 0–60 cm soil layer ranged from 98–124 kg/ha. Only in 2011 did N fertilisation result in significant differences in ear length between the treatments up to the N_3 level. The 160 kg/ha N dose (N_2) significantly rise the ear length, while the 240 kg/ha N-dose (N_3) was not significant rise ear length of barley in 2012. In 2013 the 160 and 240 kg/ha N-dose (N_2, N_3) only led to slight changes in the ear length of barley. The results showed that in 2011 and in 2012 the natural P-supplying capacity of the soil (P_0) was able to provide the AL-P_2O_5 quantity required by barley (133 and 118 mg/kg), while in 2013 the 100 kg/ha/year P treatment (P_1) gave the significantly longest ears, when the AL-P_2O_5 content of the 0–30 cm soil layer was 242 mg/kg.

The least grain number per ear was recorded in the control (N_0) plots, grains was found in the untreated (N_0) plots (13.6, 16.6, 19.0), when the mineral N content at a depth of 0–60 cm in spring was similar (98–124 kg/ha) in all the seasons investigated (2011–2013). In all the seasons 80 kg/ha N fertiliser (N_1) led to a significant rise in grain number per ear (16.4, 17.9, 19.9). Higher N supplies only resulted in a significantly higher grain number in 2011. The results showed that in 2011 and 2012 there was little change in the grain number per ear over an AL-P_2O_5 range of 118–251 mg/kg (16.1–16.9 in 2011 and 17.6–18.1 in 2012), while in 2013 better P supplies (242 mg/kg AL-P_2O_5, P_1) increased the grain number per ear from 20.1 in the control to 23.1.

N fertilisation had different effects on the thousand-grain weight in the three seasons. The highest value was recorded N_2 (160 kg/ha) treatment in 2011, at the lowest N rate (80 kg/ha) in 2012 and in the control (N_0) plots in 2013, when the N_{min} content of the 0–60 cm soil layer in spring was 109–124 kg/ha. In the seasons investigated the P supplies had no significant influence on the thousand-grain weight over an AL-P_2O_5 range of 118–251 mg/kg; the year was found to have a greater effect on this parameter.

In two of the seasons investigated (2012 and 2013) N fertilisation had a significant influence on the test weight of winter barley. The highest test weight was generally recorded 160 kg/h N-dose (N_2) at a mineral N content of 108–124 kg/ha. Excessive N fertilisation usually reduced the test weight. The AL-P_2O_5 supply levels measured in the ploughed layer in autumn 2010, 2011 and 2012 had diverse effects on the test weight of winter barley. The P fertilisation was not significant effect on the test weight in 2012. An modified in the P supplies of the soil significantly reduced the test weight in 2011, while in 2013 the P_1 treatment significant increase. The P_2 and P_3 treatments had no significant effect on this parameter.

3.4. Effect of N, P and K supplies on the grain yield of winter barley

3.4.1. Main effect of N supplies

In the seasons examined (2011–2013) the lowest yields of barley (2.22–3.39 t/ha) were obtained without N fertiliser (N_0) (Table 3).

Table 3. Effect of N supplies on the yield of winter barley, in the avarage P and K treatments (t/ha) (Szarvas, 2011–2013)

Year	Grain yield (t/ha)				$LSD_{5\%}$	Mean	Relative yield (%)
	N_0	N_1	N_2	N_3			
2011	2,22	3,33	3,77	3,58	0,15	3,23	59
2012	3,39	5,03	5,33	5,05	0,27	4,70	64
2013	2,77	4,29	4,48	4,34	0,18	3,97	62
Mean	2,79	4,22	4,53	4,32	-	3,97	62

Up to the N_2 level, increasing rates of N doses fertiliser significantly increased the yield, while the maximum rate of 240 kg/ha (N_3) generally resulted in a significant decline in the grain quantity

3.4.2. Main effect of P supplies

The natural P-supplying ability of the soil (P_0) was 118–124 mg/kg AL-P_2O_5 in the ploughed layer in the years investigated, and this resulted in varying yields in the three seasons, namely 2.96, 4.50 and 3.83 t/ha (Tabale 4). The results showed that better P supplies (an AL-P_2O_5 content of 186–244 mg/kg in the ploughed layer) led to significantly higher grain yields (3.33–4.78 t/ha).

Table 4. Effect of P supplies on the grain yield of winter barley, in the avarage N and K treatments (t/ha) (Szarvas, 2011–2013)

Year	Grain yield (t/ha)				$LSD_{5\%}$	Mean	Relative yield (%)
	P_0	P_1	P_2	P_3			
2011	2,96	3,33	3,30	3,32	0,23	3,23	89
2012	4,50	4,78	4,67	4,87	0,24	4,71	92
2013	3,83	3,94	3,94	4,26	0,25	3,99	90
Mean	3,76	4,02	3,97	4,15	-	3,98	90

3.4.3. Main effect of K supplies

It could be seen from the results that in all three seasons better K supplies (320–348 mg/kg AL-K_2O) gave higher yields than the control (K_0) level of 210–218 mg/kg (Table 5).

Table. 5. Effect of K supplies on the grain yield of winter barley, in the avarage N and P treatments (t/ha) (Szarvas, 2011–2013)

Year	Grain yield (t/ha)				$LSD_{5\%}$	Mean	Relative yield (%)
	K_0	K_1	K_2	K_3			
2011	3,07	3,62	3,26	2,95	0,24	3,23	85
2012	4,62	4,66	4,72	4,79	NS	4,70	96
2013	3,74	4,29	3,97	3,96	0,17	3,99	87
Mean	3,81	4,19	3,98	3,90	-	3,97	89

3.5. Correlation between the SPAD value of winter barley and grain yields

Figures 1–3 illustrate the relationship between the grain yield of winter barley and the SPAD values recorded at the end of tillering in the years 2011–2013. An analysis of the correlations revealed that a rise in the relative chlorophyll content was associated with an increase in yield. The polynomial trendlines characterising the SPAD index and yield exhibited a close (r=0.74; 0.84) or very close (r=0.92) correlation. The results for the three seasons suggest that the SPAD index indicative of a satisfactory N nutrition level at the end of tillering is between 43 and 52, associated with a yield of 4.0–6.0 t/ha.

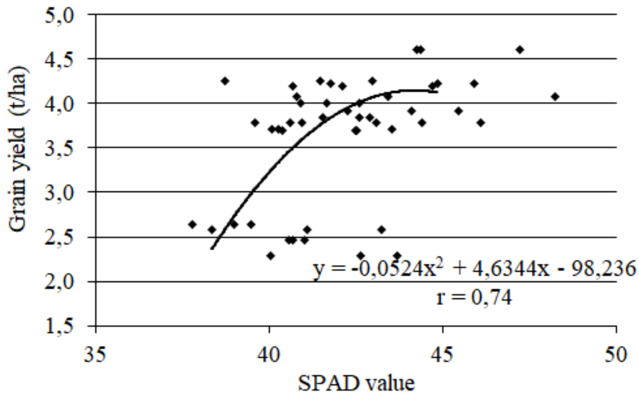

Figure. 1. Correlation between SPAD value of winter barley at end the of tillering and grain yield
(Szarvas, 2011)

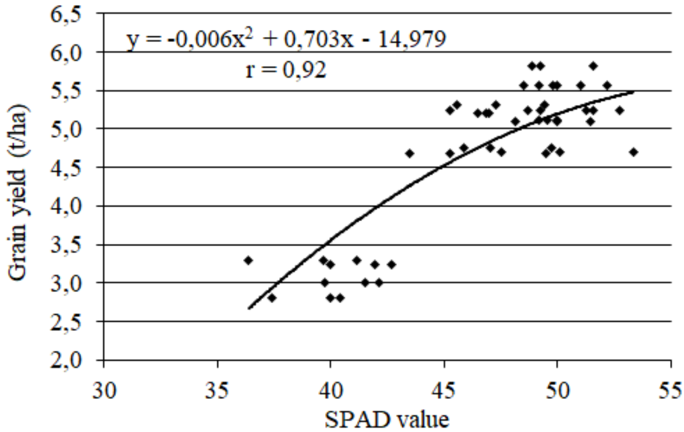

Figure. 2. Correlation between SPAD value of winter barley at the end of tillering and grain yield
(Szarvas, 2012)

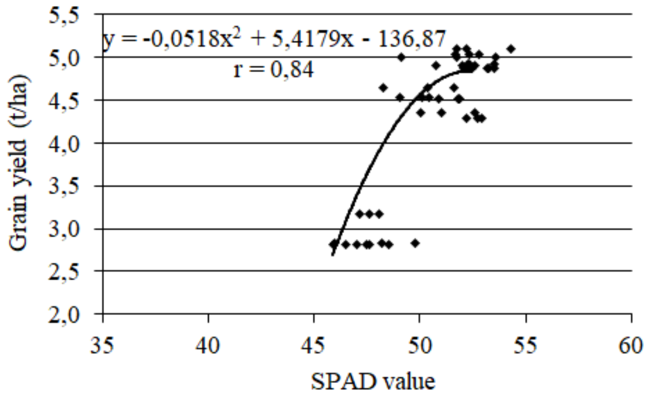

Figure.3. Correlation between SPAD value of winter barley at the end of tillering and grain yield
(Szarvas, 2013)

3.6. Correlation between nutrient concentrations of winter barley at the end of tillering and the grain yield

Correlation analysis was performed to determine the satisfactory N concentration value as follows: the grain yield and leaf N concentration data were plotted in a coordinate system and an envelope curve was fitted to the data set. Values located along the envelope curve represent cases when factors influencing the yield have optimum values and the yield is only influenced by the N concentration. At the end of tillering of winter barley the correlation between leaf N concentration and grain yield indicated that, at a yield level of over 5.0 t/ha, the limit value for satisfactory N supplies at 90% of the yield maximum, it was 3.30–4.50 N% (Figure 4.).

The limit values for satisfactory supplies of the other macronutrients (P, K, Ca, Mg, Na) and micronutrients (Mn, Zn, Cu, B, Mo) were determined by plotting the P, K, Na, Ca, Mg, Mn, Zn, Cu, B and Mo concentrations associated with the leaf N concentration and reading off the macro- and micronutrient concentrations associated with the 3.30–4.50% N concentration., which corresponded to a yield level that was at least 90% of the maximum value.

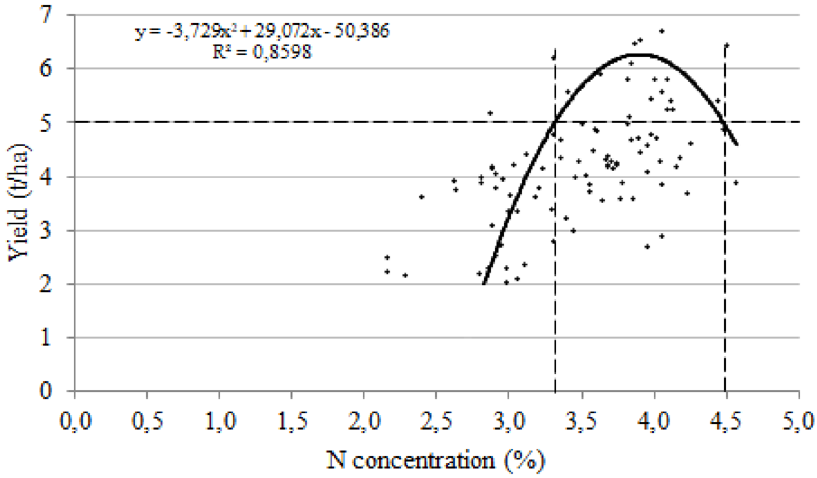

Figure 4. Relationship between N-concentration of leaf at the end of tillering and grain yield
(Szarvas, 2011-2012)

On this basis, the following nutrient concentration ranges can be considered as satisfactory for winter barley at tillering: N: 3,30-4,50%; P 0,20-0,40%; K 3,30-4,60%; Ca 0,40-0,70%; Mg 0,15-0,30%; Na 0,10-0,30%; Mn 60-75 mg/kg; Zn 20-35 mg/kg; Cu 5-9 mg/kg; B 3,50-5,00 mg/kg; Mo 0,15-0,30 mg/kg.

3.7. Effect of N and P supplies on the nutrient content of winter barley grain

In the seasons investigated (2011–2013) N fertilisation had a significant effect on the N and Mg concentration of winter barley grain. In most cases the highest concentrations of these nutrients was recorded at the maximum, 240 kg N/ha (N_3) level, with mineral N contents in spring of 158, 104 and 264 kg/ha, respectively.

P fertilisation caused significant changes in the Mg, Mn, Zn, Cu and Mo concentrations when the AL-P_2O_5 content in the ploughed layer ranged from 186–244 mg/kg.

Among the nutrient ratios of winter barley grain, the N supplies had a significant effect on the N/P, N/Ca, N/Mg and N/Cu ratios, while soil P supplies (118–251 mg/kg AL-P_2O_5) had no significant influence on the nutrient ratios with the exception of the N/Cu ratio in 2012.

3.8. New and novel scientific results

1. On chernozem meadow soil with 2.8–3.2% humus content the SPAD index indicative of satisfactory N nutrition at the beginning of winter barley tillering (39–47) can be achieved with 40 kg ha^{-1} basic N fertilisation (N_1), while 80 kg ha^{-1} basic fertilisation (N_2) is required to obtain a SPAD index of 43–52, representative of satisfactory N supplies at the end of tillering, with an AL-P_2O_5 content of 206–242 mg/kg in the ploughed layer. Soil P supplies ranging from 118–251 mg/kg AL-P_2O_5 had no significant effect on the SPAD index. The highest relative chlorophyll content was recorded when the AL-P_2O_5 content in the ploughed layer was 206–242 mg/kg.

2. At soil K and P supply levels of 320–324 mg/kg AL-K_2O and 118–251 mg/kg AL-P_2O_5, a satisfactory nutrition level for winter barley in the tillering phenophase was represented by the following nutrient concentrations: N 3.30–4.50%; P 0.20–0.40%; K 3.30–4.60%; Ca 0.40–0.70%; Mg 0.15–0.30%; Na 0.10–0.30%; Mn 60–75 mg/kg; Zn 20–35 mg/kg; Cu 5–9 mg/kg; B 3.50–5.00 mg/kg; Mo 0.15–0.30 mg/kg. In some cases these limit values are in agreement with those given in the literature, while in other cases they are novel, as narrower ranges were demonstrated for the N, Zn, Cu, Ca, Na and B concentrations, and a somewhat wider range for the K concentration. A very wide optimum range was reported in the literature for Mo, but this was found to be considerably narrower in the present work.

3. Up to a dose of 160 kg/ha (N_2), when the mineral N content of the 0–60 cm soil layer in spring was 116, 108 and 162 kg/ha, respectively, N fertilisation caused a significant increase in the yield of winter barley (3.77–5.33 t/ha). On soil containing 2.8–3.2% humus, the 240 kg/ha N_3 rate generally caused significant yield depression, reducing the yields (3.58–4.34 t/ha) compared with the maximum.

4. On chernozem meadow soil better P supplies (186–244 mg/kg AL-P_2O_5) resulted in significantly higher grain yields (3.33–4.78 t/ha) compared to the P_0 treatment, without P fertiliser, when the AL-P_2O_5 content of the ploughed layer was 118–133 mg/kg.

5. On the chernozem meadow soil type, where the AL-K_2O content of the control plots (K_0) was 210–218 mg/kg, K fertilisation significantly increased the yield of winter barley up to the K_1 level (320–346 mg/kg AL-K_2O).

6. N fertilisation had no significant effect on the various nutrient ratios at the end of tillering, but the AL-P_2O_5 content of the ploughed layer (118–251 mg/kg) significantly influenced the N/Ca, N/Mg, N/Cu and P/Zn ratios. In the case of the grain yield the N fertiliser had a significant influence, especially at higher N doses (160, 240 kg/ha) on the N/P, N/Ca, N/Mg and N/Cu ratios, but only the N/Cu ratio was affected in the case of the grain yield.

4. CONCLUSIONS AND RECOMMENDATIONS

SPAD index

The SPAD index of winter barley in the early stage of tillering (Feekes 2–3) was 37.8, 34.3 and 46.7, averaged over the P treatments, in the three seasons, when the NO_3^--N content of the 0–30 cm soil layer in autumn, prior to N fertilisation, was 22, 46 and 21 kg/ha, respectively. A SPAD index of 39–47 can be recommended as characteristic of satisfactory N nutrition, which could be achieved with basic N fertilisation of 40 kg/ha on chernozem meadow soil.

At the end of tillering (Feekes 5–6) the SPAD index was significantly higher than in the control (N_0) when basic N fertiliser was applied up to 80 kg/ha (N_2), with values of 40.6, 40.3 and 47.5. In this phenophase a SPAD index of 43–52 can be considered as satisfactory, which could be ensured with 80 kg/ha N topdressing (N_2), when the mineral N content in the 0–60 cm soil layer in spring was 108–162 kg/ha in the seasons investigated. Excessive N basic fertiliser supplies (120 kg N/ha, N_3) had no significant effect on the relative chlorophyll content of the leaves.

The AL-P_2O_5 content of the soil had no significant influence on the SPAD values recorded for winter barley at the beginning and end of tillering, though higher relative chlorophyll contents were obtained when the AL-P_2O_5 content of the ploughed later was 206–251 mg/kg.

Nutrient content at tillering

Compared to the treatment given no N fertiliser (N_0), higher rates of N fertilisation significantly increased the nutrient concentrations of N, K, Ca and Mn in 2010/2011, but only resulted in a slight rise in the P, Mg, Na, Zn and Mo concentrations of barley leaves. In both seasons investigated (spring 2011 and 2012) pronounced N/B antagonism was observed; rising rates of N fertiliser tended to decrease the B concentration. In the 2011/2012 season N fertilisation only led to a significant increase in the N, Mn and Zn levels compared with the N_0 control, while only slightly higher values were recorded for the K, Ca, Na and Cu concentrations. The highest nutrient concentrations, for both macro- and micronutrients, were generally found in the 240 kg/ha (N_3) treatment.

When the nutrient status of winter barley was examined at tillering in the 2010/2011 season the P supplies of the soil only caused a significant rise in the P concentration. In 2011/2012, however, the concentrations of not only N, P, Mg and B, but also of K, Ca and Cu concentrations were improved by better P supplies, despite the well-known P antagonism for these elements. Significant increases in the nutrient concentrations were recorded when the AL-P_2O_5 content of the ploughed layer ranged from 186–233 mg/kg.

Based on the correlation between leaf N concentration and the grain yield, the limit value for satisfactory N supplies in the tillering phenophase of winter barley a yield level of over 5.0 t/ha the limit value for satisfactory N supplies at 90% of the yield maximum, it was 3.30–4.50 N%. Satisfactory supplies of other macronutrients (P, K, Ca, Mg, Na) and micronutrients (Mn, Zn, Cu, B, Mo) could be achieved with the following nutrient concentrations: P 0.30–0.50%; K 2.80–5.00%; Ca 0.40–0.80%; Mg 0.15–0.30%; Na 0.10–0.30%; Mn 50–80 mg/kg; Zn 20–35 mg/kg; Cu 5–9 mg/kg; B 3.50–6.00 mg/kg; Mo 0.15–0.30 mg/kg. Some of these limit values confirmed those previously given in the literature (Elek and Kádár 1980, Reuter and Robinson 1997, Sanchez 2007), but others represented novel results, as narrower ranges of N, Zn, Cu, Ca, Na and B concentrations and somewhat wider ranges of K concentrations were determined in the present work. The very wide range of Mn concentrations found in the literature was substantially narrowed on the basis of the experiments.

Nutrient ratios at tillering

N fertilisation had no significant effect on the nutrient ratios of barley at tillering in any of the seasons. On the other hand, an increase in the P supplies of the soil from 118–133 mg/kg AL-P_2O_5 in the control to 186–251 mg/kg AL-P_2O_5 significantly reduced the N/Ca and N/Mg ratios of winter barley at tillering in 2012. In 2011 the N/Cu ratio was smaller when the AL-P_2O_5 content of the ploughed layer was greater than 200 mg/kg. In 2011 there was a slight rise in the P/Zn ratio (i.e. the Zn concentration declined compared to that of P) from 169 in the control to 174 and 183 at AL-P_2O_5 contents in the ploughed layer of 206 and 196 mg/kg, respectively. An AL-P_2O_5 content of 251 mg/kg, however, led to a significant increase in the P/Zn ratio.

Nutrient content of the grain yield

In the three seasons tested (2011–2013) N fertilisation had a significant effect on the N and Mg concentrations in the grain of winter barley. The highest nutrient concentrations were generally found at the maximum N rate (240 kg N/ha, N_3).

P fertilisation significantly influenced the Mg, Mn and Mo concentrations of the grain in the individual seasons when the AL-P_2O_5 content of the ploughed layer was between 186 and 244 mg/kg. Compared to the control (118–133 mg/kg AL-P_2O_5), a rise in the soil P supplies (186–251 mg/kg) generally caused a significant reduction in the Zn and Cu content in 2012 due to the P/Zn and P/Cu antagonism.

Among the nutrient ratios of winter barley grain, the N supplies had a significant effect on the N/P, N/Ca, N/Mg and N/Cu ratios, while soil P supplies (118–251 mg/kg AL-P_2O_5) had no significant influence on the nutrient ratios with the exception of the N/Cu ratio in 2012

Yield characteristics

The results showed that increasing rates of N fertiliser (80, 160, 240 kg/ha), when the mineral N content of the 0–60 cm soil layer in spring was 158, 104 and 264 kg/ha respectively, generally caused a significant increase in the straw length of winter barley up to the N_3 level (51.8–75.8 cm). In the seasons examined (2011–2013) changes in soil P supplies had no significant influence on the straw length of barley. The natural AL-P_2O_5-supplying ability of the soil (118–133 mg/kg) was sufficient to achieve satisfactory straw length.

The results achieved in all three seasons showed a significant increase in ear length (6.2–7.7 cm) in the N_1 treatment (80 kg N/ha), while higher N rates only gave significantly longer ears (6.6 and 7.0 cm) in 2011. The 160 kg/ha N-dose (N_2) rised significantly the ear length, while the 240 kg/ha N-dose (N_3) was not significant on the ear length of barley in 2012. In 2013 the N_2 and N_3 treatments (160 and 240 kg N/ha) only led to slight changes in the ear length of barley. Without P fertiliser (P_0), when the AL-P_2O_5 content of the ploughed layer was 133 and 188 mg/kg in 2011 and 2012, respectively, the ear length of winter barley was 6.4 and 6.8 cm, and no substantial change was recorded when the P supplies of the soil were enhanced (6.2–7.0 cm). In 2013, however, P fertilisation proved to have a significant effect on the ear length, which reached 8.1 cm when the AL-P_2O_5 content of the ploughed layer was 242 mg/kg.

In all three seasons 80 kg/ha N fertilisation (N_1) resulted in a significant increase in the grain number per ear, from 16.4–19.9, while higher N rates only increased the grain number to a significant extent in 2011 (17.5 and 18.2). In 2011 and 2012 the results showed that AL-P_2O_5 contents of 133 and 118 mg/kg were associated with 16.9 and 17.6 grains/ear, while higher P supplies (186–251 mg/kg AL-P_2O_5) caused no significant change in the grain number (16.1–18.1). In 2013, however, a soil AL-P_2O_5 content of 242 mg/kg led to a significantly higher grain number per ear (23.1).

N fertiliser had different effects on the thousand-grain weight in the three seasons. The highest value was recorded in the maximum N_2 (160 kg/ha) treatment in 2011, at the lowest N rate (80 kg/ha) in 2012 and in the control (N_0) plots in 2013, when the N_{min} content of the 0–60 cm soil layer in spring was 109–124 kg/ha. The increasing N fertilisation led to a significant decrease the thousand-grain weight. The negative effect of N fertiliser on the thousand-grain weight was also reported by other authors (Munir 2002, Slamka et al. 2008, Cai et al. 2012, Berhanu et al. 2013). According to Draskovits (2013) P supplies improved the thousand-grain weight of cereals, but this was not confirmed in the present work, the year was found to have a greater effect on this parameter.

In the seasons tested the highest test weight was obtained at diverse N levels (N_2, and N_0, respectively), when the mineral N content recorded in spring ranged from 108–124 kg/ha. Excessive N fertilisation, however, generally reduced the test weight of barley. The AL-P_2O_5 contents of the ploughed layer in autumn 2010, 2011 and 2012 influenced the test weight of barley to different extents. In 2011 the highest test weight (73.4 kg) was recorded in the control (133 mg/kg AL-P_2O_5), and this significantly declined (71.8–72.2 kg) as the soil P supplies rose (194–251 mg/kg AL-P_2O_5). In 2013, however, better soil P supplies resulted in significantly greater test weights compared to the control, while in 2012 the P content of the ploughed layer had no effect on the test weight.

Grain yield

Increasing rates of N fertiliser significantly improved the yield of winter barley, with the highest yield in the N_2 treatment (160 kg N/ha), when the N_{min} content of the 0–60 cm soil layer in spring was 109–162 kg/ha. The maximum N rate (240 kg/ha) caused yield depression in all three seasons, leading to lower yields. On chernozem meadow soil with 2.8–3.2% humus content 40 kg/ha basic N fertilisation and 80 kg/ha N topdressing can be recommended.

The analysis of the main effect of P revealed that, compared with the control (118–133 mg/kg AL-P_2O_5), a significant yield increase could be obtained with an AL-P_2O_5 content of 206–242 mg/kg. Consequently, on chernozem meadow soil P fertilisation can be recommended for winter barley up to soil AL-P_2O_5 contents of 200–250 mg/kg.

It could be seen from the analysis of the main effect of K that a yield of 3.07–3.74 t/ha could be achieved without K fertiliser on chernozem meadow soil when the soil AL-K_2O content was 210–218 mg/kg. In each seasons better soil K supplies resulted in higher yields. On this heavy, clayey loam chernozem meadow soil K fertilisation may continue to enhance the yield even at soil AL-K_2O contents of 300–350 mg/kg.

From the point of view of yield, the most favourable nutrient ratios at tillering were as follows:

N/P 8,5-13,3	P/Mg 1,3-2,3	K/Cu 5973-6006	Ca/Mg 2,6
N/Ca 6,8-7,6	P/Zn 98-184	K/Mg 17,2-19,2	
N/Mg 17,8-19,4		K/Na 17,5-17,8	
N/Cu 5429-6751			

The N fertilisation of winter barley is satisfactory if the straw length is 51.3–71.4 cm, the ear length 6.6–7.5 cm, the grain number per ear 17.5–20.1, the thousand-grain weight 40.8–46.6 g and the test weight 65.0–72.7 kg.

The AL-P_2O_5 content of the soil at the beginning and end of tillering had no significant effect on the SPAD index of winter barley, while a significant increase in the nutrient concentrations was obtained with 186–233 mg/kg AL-P_2O_5 in the ploughed layer at tillering and with 186–244 mg/kg for the grain yield. An AL-P_2O_5 content of 118–133 mg/kg in the ploughed layer (P_0) proved to be sufficient for winter barley with respect to the straw length, ear length and grain number per ear, while the thousand-grain weight and test weight were modified to varying extents by the soil P supplies. The results suggested that favourable yields of winter barley could be achieved with P fertilisation to a soil P supply level of 200–250 mg/kg AL-P_2O_5 in the ploughed layer.

On chernozem meadow soil an AL-K_2O content of 320–346 mg/kg in the 0–30 cm soil layer is favourable for winter barley.

5. PUBLICATIONS

5.1. Publications related to the subject of the thesis

Impact factor article

Surányi Sz., Izsáki Z. (2018): Plant analysis application for environmentally friendly fertilization of winter barley (*Hordeum vulgare L.*). Applied Ecology and Environmental Research 16 (4): 5213-5226.

Peer-reviewed hungarian language journal articles

Surányi Sz., Izsáki Z. (2018): A P-trágyázás hatása az őszi árpa (*Hordeum vulgare L.*) bokrosodáskori tápelem-koncentrációjára tartamkísérletben Növénytermelés 67(1):31-48.

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Surányi Sz., Izsáki Z. (2012): Effect of water supply on the NO_3-N turnover in longterm mineral fertilisation experiment. 11. Alps Adria Scientific Workshop, Smolenice, Slovakia, 26-31 March.

5.2. Other publications

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