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Effect of Rising Dose of NPK Fertilizers on Weeds of Grain Sorghum (*Sorghum bicolor*) on a Calcareous Loamy Chernozem Soil

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ABSTRACT

The effect of different NPK levels (poor, satisfactory, excessive and toxic) and combinations of these on the soil cover percentage of natural weed flora of grain sorghum (*Sorghum bicolor*) was studied on a loamy chernozem soil with lime deposit. The N levels were 0 (poor), 100 (satisfactory), 200 (excessive) and 300 (toxic) kg ha^{-1} $year^{-1}$; P and K fertilizing was done with 0 (poor), 500 (satisfactory), 1000 (excessive), 1500 (toxic) kg ha^{-1} P_2O_5 and K_2O refilling doses. Later only sustaining of PK levels were targeted, reapplication was repeated every 5-10 years. P and K fertilizer and half of the N fertilizer was spread in autumn before ploughing the plots, the other half of N was spread in spring in the form of 25-28% calcium ammonium nitrate, 18% superphosphate and 40-60% potassium chloride. The mineral fertilization experiment series was initiated in autumn 1973. Different crops were produced on these plots annually. Grain sorghum was sown in 1992. This long-term experiment series consisted of 4N × 4P × 4K= 64 treatments, or nutritional levels, in two replications, giving a total of 128 plots. The plot size was 6 × 6 = 36 m^2 in mixed factorial design. Weed surveys were done in 4 m^2 quadrats in two replications and contained not only weed flora but crop cover, too. The number of weed species, the weed and crop soil cover were highly dependent upon the doses and ratio of different fertilizers.

Keywords: combination of fertilisers, nutritional level, sorghum cover, weed cover
Abbreviations: K, potassium; **N**, nitrogen; **P**, phosphorus

INTRODUCTION

Grain sorghum (*Sorghum bicolor* L.) is a major cereal crop in semi-arid tropical regions (Khanna-Chopra and Kumari 1995). In a US experiment (Sweeney *et al.* 2011) objectives were to determine the effects of phosphorus (P) and potassium (K) fertility levels, nitrogen (N) application and legume residual on grain sorghum production. Following alfalfa and birdsfoot trefoil, first-year sorghum yield was 7 kg ha^{-1} and was not affected by N fertilizer. In subsequent years, the N inflected yield increase was less than 20%. Sorghum yield increased at low P and K rates, especially with nitrogen (N) fertilization and was greater following birdsfoot trefoil than following alfalfa. Grain sorghum grown after legume crops required minimal levels of P and K, especially when N fertilizer was added.

Sorghum is known to respond with favourable grain yields up to 120 kg N ha^{-1} (Muchow 1988). Three nitrogen levels (0, 75 and 150 kg ha^{-1}) were applied in three grain sorghum cultivars in a Turkish experiment (Güller *et al.* 2008). Generally, N had no effect on plant height and stalk length. The effect of N on grain yield per plant was usually insignificant. Nitrogen has positively affected grain yield per unit area. It might be concluded that increased nitrogen generally gives the best results in grain yield and yield components in sorghum.

When N-fertilizer is applied, variable response was observed depending on the amount of available water. Khanna-Chopra and Kumari (1995) examined the response of hybrid grain sorghum for N-application under variable water availability. N-fertilizer at the rate of 40 kg N ha^{-1} was spread on half of the plots prior to planting while the remaining half received no N-fertilizer. Available soil N in plots unfertilized with N was 25 kg ha^{-1}. Irrigation of 60mm was given on the 30th day after seeding in two thirds of the plot while one third of the same plots received additional irrigation (60 mm) on the 60th day after sowing. Total rainfall during the crop season was 170 mm. Addition of N-fertilizer had no significant effect on the yield of unirrigated plants. A single irrigation increased yield 2.5 to 3.0-fold in unfertilized and fertilized plants, respectively. Grain yield in fertilized plots were double those observed in unfertilized plots. One additional irrigation doubled the yield in unfertilized plots while similar treatment in the fertilized plots did not increase the yield significantly.

A small dose of N fertilizer increased the diversity of herbaceous plants in an arid environment in India (Singh and Shukla 2011) while a 100-150 kg ha^{-1} $year^{-1}$ dose caused decreases in a wet environment (tropical forest) in China (Lu *et al.* 2010).

In a wetland of Somerset, when higher rates (75 kg ha^{-1} $year^{-1}$) of phosphorus were included biomass increased very significantly, but species diversity was severely reduced (Kirkham *et al.* 1996).

Phosphorus fertilizer is a major input in crop production as many soils lack sufficient P to maximize crop yield (Grant *et al.* 2001).

The crop fertility recommendations rarely consider that added nutrients might enhance weed growth, as well as crop growth, and that the resulting crop–weed competitive interactions can be influenced by fertilizer (Blackshaw and Brandt 2009).

This paper describes the effect of different NPK levels and their combinations on the soil cover percentage of natural weed flora of grain sorghum (*Sorghum bicolor*) on a loamy chernozem soil with lime deposit. This experiment

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Original Research Paper

Table 1 Agronomic measures and surveys done in grain sorghum experiment in 1992 (calcareous loamy chernozem soil, Nagyhörcsök, Mezőföld) 50 cm row distance, 3-5 cm sowing depth, with 20 kg ha^{-1} sowing seed.

Agronomic measures, surveys	Day, month, year	Comment
1. NPK fertilizer spreading	05. 12. 1991	by hand, plot by plot
2. Ploughing	05. 12. 1991	MTZ-80 + Lajta plough
3. Finishing	06. 04. 1992	MTZ-50 + harrow
4. N-fertilizer spreading	08. 05. 1992	by hand, plot by plot
5. Incorporation of fertilizer	08. 05. 1992	MTZ-80 + disc
6. Seedbed preparation	08. 05. 1992	MTZ-80 + combinator
7. Sowing (cv. 'Alföld-1')	11. 05. 1992	MTZ-50 + SPC sowing machine
8. Rolling	11. 05. 1992	MTZ-50 + ring roller
9. Alignment of plots	27. 05. 1992	by hand
10. Weed and crop survey	03. 07. 1992	plot by plot
11. Herbicide spraying	08. 07. 1992	whole experiment (Atrazin)
12. Harvesting	06. 11. 1992	combine, plot by plot

was performed in 1992 but this data set was not yet published in detail, not even in Hungarian, because mainly the yield and chemical composition of the crop was in focus and not the ground cover of the crop and weeds.

MATERIALS AND METHODS

The present experiment was conducted in 1992, as part of a long-term experiment established in 1973 at Mezőföld at an experimental station belonging to the Research Institute for Soil Science and Agricultural Chemistry, the Hungarian Academy of Sciences in Nagyhörcsök. Sorghum was produced only once, in the 19th year of the long-term experiment, in 1992. The production site's soil was calcareous loamy chernozem soil and contained 3% humus, 5% $CaCO_3$ and 20% clay in the ploughed layer. pH(KCl) was 7.3, AL-P_2O_5 60-80 mg kg^{-1}, AL-K_2O 140-160 mg kg^{-1}, KCl-Mg 150-180 mg kg^{-1}, EDTA-Mn 80-150 mg kg^{-1}, EDTA-Cu 2-3 mg kg^{-1}, and EDTA-Zn 1-2 mg kg^{-1}. These data show that the soil was supplied poorly with P and Zn and moderately well with N and K, well with Mg and Cu and very well with Mn. The groundwater was at a depth of 13-15 m and the area was susceptible to drought.

P and K fertilizer and half of the N fertilizer was spread in autumn before ploughing the plots, the other half of N was spread in spring in the form of 25-28% calcium ammonium nitrate, 18% superphosphate and 40-60% potassium chloride. The N levels were 0, 100, 200 and 300 kg ha^{-1} per annum, P and K fertilizing was done with 0, 500, 1000, 1500 kg ha^{-1} P_2O_5 and K_2O refilling doses. Later only sustaining of PK levels was targeted, refilling was repeated every 5-10 years with slow-acting P and K fertilizers. In Hungary, this refilling is usually done with reserve fertilizing method every 5-10 years. In 1973, the experiment consisted of 4N × 4P × 4K= 64 treatments, or nutritional levels, in two replications, giving a total of 128 plots. The plot size was 6 × 6 = 36 m^2 in a mixed factorial design. Experimental plan and doses of fertilizers allowed every nutritional level to be established as well as those combinations that occurred or will occur in practice (Kádár and Elek 1999).

The experiment's crop succession was as follows: winter wheat (2 years) corn (2 years), potato, winter barley, oat, sugar rape, sunflower, poppy, rapeseed, mustard, spring barley, linseed, soybean, hemp, peas, and triticale. In the 19th year of the experiment grain sorghum cv. 'Alföld-1' was produced. Sowing was on 11th May 1992, with 50 cm row distance, at 3-5 cm depth and with 20 kg ha^{-1} seed quantity. During the growing season a survey of the crop stand and weeds was made in July before herbicide spraying.

Agronomic measures and surveys in the experiment are shown in **Table 1** in chronological order.

Weed surveys were done in 4 m^2 quadrats in two replications and contained not only weed flora but cover of the crop, too (Hunyadi 1988; Reisinger 2000).

Regarding precipitation, the year 1992 was much drier (470 mm) than average (590 mm). After harvesting the forecrop, triticale, in 1991, between the end of July and the end of December, 268 mm precipitation was detectable at the experimental area. In 1992, prior to the sowing of sorghum in May, 52 mm more fell. During the growing season the following amount had fallen: 9 mm in May, 156 mm in June, 14 mm in July, 3 mm in August, 17 mm in September, and 125 mm in October, a total of 324 mm in an extremely uneven distribution. Theoretically plants received 268 + 52 + 324 = 644 mm water in the case that the soil stored precipitation suitably in the root zone.

Statistics

Collected data were analysed according to Sváb (1981) and by IBM SPSS Inc. PASW Statistics 18 software.

Means were compared by one-way ANOVA. Weed cover data from the survey were compared with one-way comparison of independent samples in which the software counts with means and decides that weed cover data are homogeneous or different. Standard deviations are indicated on the graphs.

For multivariate analysis, correspondence analysis (CA) was used. CA or reciprocal averaging finds a set of synthetic variables that summarise the original set. The underlying model assumes chi-squared dissimilarities among records (cases).

RESULTS AND DISCUSSION

Weed species

Weed species of the experiment were: tumbleweed (*Amaranthus albus*) with average 0.01% ground cover, prostrate amaranth (*Amaranthus blitoides*) 17.5%, redroot pigweed (*Amaranthus retroflexus*) 2.85%, small toadflax (*Chaenorrhinum minus*) 0.01%, white goosefoot (*Chenopodium album*) 0.67%, maple-leaved goosefoot (*Chenopodium hybridum*) 0.54%, creeping thistle (*Cirsium arvense*) 0.25%, field bindweed (*Convolvulus arvensis*) 0.18%, jimson weed (*Datura stramonium*) 0.19%, hairy crabgrass (*Digitaria sanguinalis*) 0.12%, annual wall-rocket (*Diplotaxis muralis*) 0.05%, common barnyard grass, (*Echinochloa crus-galli*) 0.12%, sun spurge (*Euphorbia helioscopia*) 0.01%, black-bindweed (*Fallopia convolvulus*) 0.05%, European turnsole (*Heliotropium europaeum*) 0.04%, annual meadow grass (*Poa annua*) 0.13%, common purslane (*Portulaca oleracea*) 0.15%, wild mignonette (*Reseda lutea*) 0.45%, green foxtail (*Setaria viridis*) 0.12%, fluxweed (*Sisymbrium sophia*) 0.15%, annual woundwort (*Stachys annua*) 0.01%.

Dominant weed species was prostrate amaranth (*Amaranthus blitoides*) with its 17.5% average soil cover. The one with the second highest (2.85%) average cover was the redroot pigweed (*Amaranthus retroflexus*). All other species covered less than 1% of the soil at the time of weed survey. White goosefoot (*Chenopodium album*) and maple-leaved goosefoot (*Chenopodium hybridum*) reached 0.5% average cover. Average cover of grain sorghum in the experiment was 45.8% at the time of the weed survey.

Ground cover of grain sorghum

From precipitation data mentioned in the chapter 'Materials and methods', it is observable that May, July, August and September experienced drought and June and October were

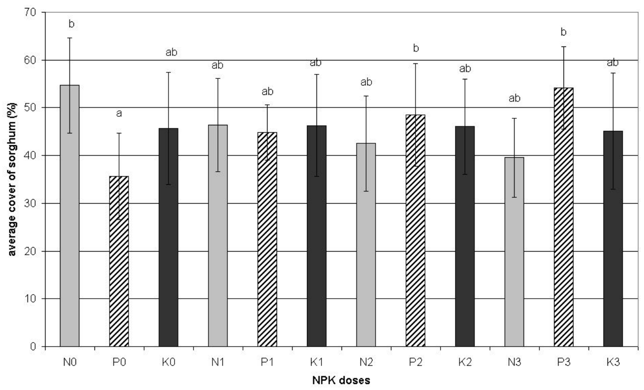

Fig. 1 Average soil cover (%) of grain sorghum according to different NPK fertilizer doses. (N0) 0 N kg ha^{-1} per year, (N1) 100 N kg ha^{-1} per year, (N2) 200 kg ha^{-1} per year, (N3) 300 kg ha^{-1} per year, (P0) 0 P kg ha^{-1}, (P1) 500 P kg ha^{-1}, (P2) 1000 P kg ha^{-1}, (P3) 1500 P kg ha^{-1}; (K0) 0 K kg ha^{-1}, (K1) 500 K kg ha^{-1}, (K2) 1000 K kg ha^{-1}, (K3) 1500 K kg ha^{-1}. Standard deviations are indicated on the graphs with error bars. Significant differences on level p≤0.05% are indicated with different lower case letters above the bars.

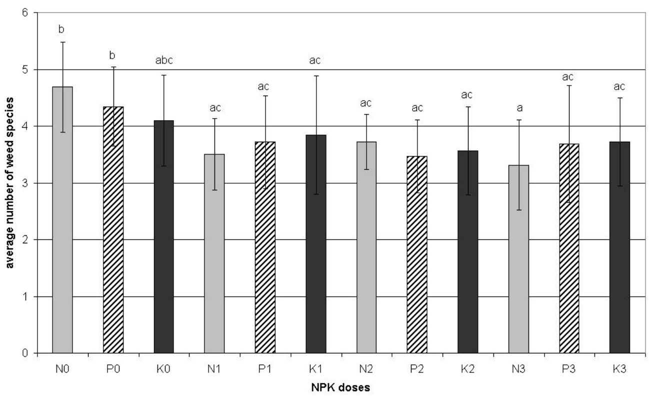

Fig. 2 Average number of weed species according to different NPK fertilizer doses. (N0) 0 N kg ha^{-1} per year, (N1) 100 N kg ha^{-1} per year, (N2) 200 kg ha^{-1} per year, (N3) 300 kg ha^{-1} per year, (P0) 0 P kg ha^{-1}, (P1) 500 P kg ha^{-1}, (P2) 1000 P kg ha^{-1}, (P3) 1500 P kg ha^{-1}; (K0) 0 K kg ha^{-1}, (K1) 500 K kg ha^{-1}, (K2) 1000 K kg ha^{-1}, (K3) 1500 K kg ha^{-1}. Standard deviations are indicated on the graphs with error bars. Significant differences on level p≤0.05% are indicated with different lower case letters above the bars.

very moist months. Because of the dry May initial development of sorghum was very slow and the crop was not able to compete with weeds. On the other hand, the moist October caused a late harvest.

Average cover of the crop (**Fig. 1**) decreased consequently but not significantly by increasing the dose of N fertilizer. The fact that even the lowest dose of N did not increase cover of sorghum is very interesting in light of the proved yield increasing effect of 120-150 kg N ha^{-1} (Muchow 1988; Güller *et al.* 2008). On the other hand, higher grain yield does not necessarily mean the crop has higher soil cover.

Contrarily, phosphorus gave a positive effect on grain sorghum on this poorly P-supplied soil. Increasing P-doses increased crop cover significantly in the case of the two higher P-doses, where this macroelement was necessary to give a dense sorghum stand.

K-fertilizing had no detectable effect on the cover of the crop (Sweeney *et al.* 2011).

Average number of weed species

Average number of weed species (**Fig. 2**) was influenced by ascendant N doses. Compared to zero N dose, average num-

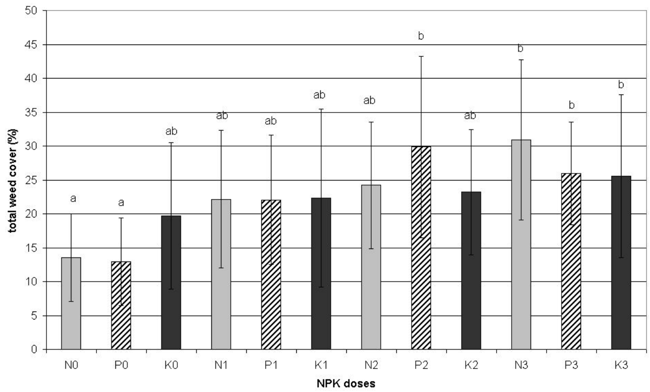

Fig. 3 Average total weed cover (%) according to different NPK fertilizer doses. (N0) 0 N kg ha^{-1} per year, (N1) 100 N kg ha^{-1} per year, (N2) 200 kg ha^{-1} per year, (N3) 300 kg ha^{-1} per year, (P0) 0 P kg ha^{-1}, (P1) 500 P kg ha^{-1}, (P2) 1000 P kg ha^{-1}, (P3) 1500 P kg ha^{-1}; (K0) 0 K kg ha^{-1}, (K1) 500 K kg ha^{-1}, (K2) 1000 K kg ha^{-1}, (K3) 1500 K kg ha^{-1}. Standard deviations are indicated on the graphs with error bars. Significant differences on level p≤0.05% are indicated with different lower case letters above the bars.

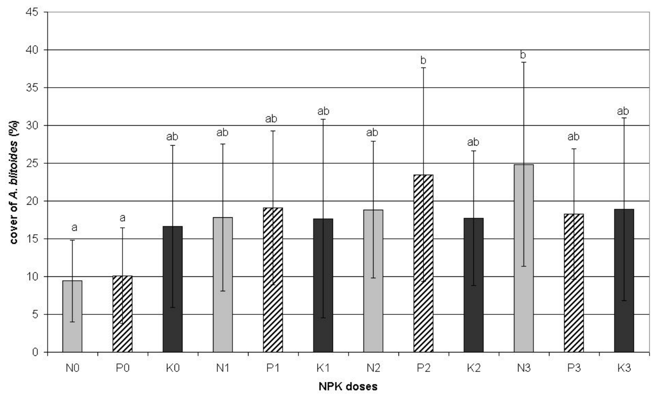

Fig. 4 Average soil cover (%) of *Amaranthus blitoides* according to different NPK fertilizer doses. (N0) 0 N kg ha^{-1} per year, (N1) 100 N kg ha^{-1} per year, (N2) 200 kg ha^{-1} per year, (N3) 300 kg ha^{-1} per year, (P0) 0 P kg ha^{-1}, (P1) 500 P kg ha^{-1}, (P2) 1000 P kg ha^{-1}, (P3) 1500 P kg ha^{-1}; (K0) 0 K kg ha^{-1}, (K1) 500 K kg ha^{-1}, (K2) 1000 K kg ha^{-1}, (K3) 1500 K kg ha^{-1}. Standard deviations are indicated on the graphs with error bars. Significant differences on level p≤0.05% are indicated with different lower case letters above the bars.

ber of weed species, diversity of weed flora decreased significantly with all three doses of nitrogen (N1, N2, N3). This can be confirmed by the results of several experiments (Bobbink 1991; Lu *et al.* 2010; Singh and Shukla 2011).

Ascendant dose of P (Kirkham *et al.* 1996) and K (Pywell *et al.* 2007) had no significant effect on average number of weed species but a moderate decreasing tendency can be observed in the case of these two macroelements, too.

Total weed cover and average ground cover of main weed species

Total weed cover was clearly influenced by ascendant N doses (**Fig. 3**). 300 kg ha^{-1} dose increased total weed cover significantly compared to zero dose of N. On the other hand in a Pakistani experiment (Saeed *et al.* 2010) the crop tolerated better weed competition when a high dose (200 kg ha^{-1}) of nitrogen was available.

Phosphorus also increased weed cover. P2 (1000 kg P ha^{-1}) increased it more than the highest dose (P3: 1500 kg P ha^{-1}). Nevertheless, both higher doses (P2, P3) showed significantly higher weed cover than zero dose (P0).

Table 2 Means and standard deviations of cover of three weed species: *Amaranthus retroflexus*, *Chenopodium album* and *Chenopodium hybridum*.

NPK doses	Mean (%)	Standard deviation
Cover of *Amaranthus retroflexus*		
N0	1.63	2.28
P0	0.53	0.52
K0	0.88	1.09
N1	2.64	3.46
P1	0.78	0.77
K1	2.65	5.38
N2	2.62	4.55
P2	3.54	5.25
K2	3.17	5.22
N3	4.51	7.74
P3	6.55	6.96
K3	4.69	6.09
Cover of *Chenopodium album*		
N0	0.91	0.78
P0	0.41	0.43
K0	0.43	0.44
N1	0.74	0.60
P1	0.74	0.67
K1	0.57	0.50
N2	0.55	0.37
P2	0.84	0.61
K2	0.82	0.69
N3	0.48	0.59
P3	0.69	0.67
K3	0.86	0.72
Cover of *Chenopodium hybridum*		
N0	0.20	0.26
P0	0.30	0.47
K0	0.44	0.45
N1	0.40	0.52
P1	0.56	0.56
K1	0.30	0.41
N2	1.09	2.49
P2	0.85	2.45
K2	0.25	0.28
N3	0.45	0.49
P3	0.44	0.76
K3	1.16	2.50

Potassium slightly increased total weed cover but not significantly.

Average soil cover of prostrate amaranth (*A. blitoides*) was increasing with ascendant dose of N and significant difference was observable between the zero (N0) and the highest (N3) doses (**Fig. 4**).

An increasing dose of P also enhanced the cover of this weed species, but only until reaching P2 dose (1000 P kg ha^{-1}) where the difference can be proved statistically compared to zero dose (P0).

K-fertilizing had no detectable effect on the cover of prostrate amaranth.

Significant differences were not found in the case of any other weed species but some tendencies are observable. Weed species with the second highest soil cover, redroot pigweed (*Amaranthus retroflexus*) clearly – but not significantly – followed the ascending doses of all three macro elements with its soil cover (**Table 2**).

No significant differences can be observed in the case of white goosefoot (*Chenopodium album*). Cover of this species decreased (**Table 2**) with increasing N doses and increased with increasing K doses. Effect of phosphorus was not so obvious. Like in the case of total weed cover (**Fig. 2**) and cover of *A. blitoides* (**Fig. 4**), increasing dose of P also enhanced cover of this weed species but only until reaching P2 dose (1000 P kg ha^{-1}).

Vengris *et al.* (1955) reported that P fertilization increased the growth of common lambsquarters (*Chenopodium album* L.) and redroot pigweed (*Amaranthus retroflexus* L.) more than that of maize (*Zea mays* L.), which could be confirmed by the present experiment too.

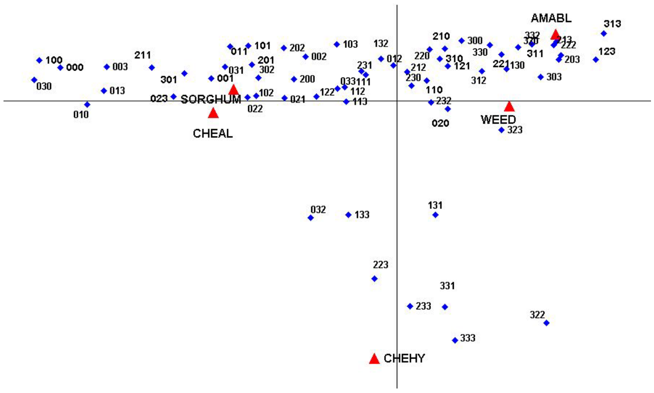

Fig. 5 Correspondence analysis of the crop (SORGHUM) the three weed species (AMABL, CHEHY, CHEAL), total weed cover (WEED) and related combinations of fertilizer doses. First digit of the triple-digit code is for N dose, second is for P dose and third is for K dose. 0 = no treatment, 1 = 100 kg ha^{-1} N, 500 kg ha^{-1} P_2O_5 or K_2O; 2 = 200 kg ha^{-1} N, 1000 kg ha^{-1} P_2O_5, or K_2O; 3 = 300 kg ha^{-1} N, 1500 kg ha^{-1} P_2O_5, or K_2O.

Increasing dose of N and P also enhanced the cover of maple-leaved goosefoot (*Chenopodium hybridum*) but only until reaching N2 (200 kg ha^{-1} year^{-1}) and P2 dose (1000 P kg ha^{-1}). No significant difference was found (**Table 2**).

Combinations of different NPK doses

Correspondence analysis (**Fig. 5**) shows the places of the crop, three weed species and total weed cover in the areas defined by different combinations of fertilisers. This method places the different factors in a frame of reference (map), like the cover of the crop (SORGHUM), the three weed species (AMABL, CHEHY, CHEAL), total weed cover (WEED) and related combinations of fertilizer doses.

Those treatments (combinations of doses) that are in the same half of the map – vertically or horizontally – constitute a group, while those in the other half of the map distinctly differ from one another. Distance between a factor and a combination of fertilizer doses indicates the strength of connection between the given combination of doses and the factor. The closer the point is to the factor the more typical it is of it. Combinations of doses on the edge of the map or close to the edge are the most characteristic ones and they are the distinctive characteristics of the factor that are the closest to them. The further a combination of doses is from the edge of the map, hence the closest to the zero point, the less it could be called characteristic – these are the general characteristics of the examined category. Those points that are between the zero point and the factor could also be connected with the factor, but they are not distinctive characteristics of the factor because they are shared with other factors.

Many of the combinations with 0 nitrogen dose are strongly related to the crop (SORGHUM), proving the observation from **Fig. 1** where cover of sorghum is the highest in the zero dose of nitrogen. Simultaneously the highest dose of P is connected with sorghum, but it seems to be not so an important characteristic, as far as many of the combinations with zero dose P are between SORGHUM and the edge of the map.

Total weed cover (WEED) and combinations of 323 and 322 are the closest to each other. Weeds generally adapt well to any circumstances and utilize nutrients well (Hunyadi 1988), better than crops.

313 is the best combination for prostrate amaranth (AMABL). As this species gave the highest portion of the total weed cover, it can be said that it is highly related to nitrogen. This could be the cause of the highest cover of sorghum at zero nitrogen dose, that prostrate amaranth is a

better competitor for nitrogen and hindered the development of sorghum when much nitrogen was available.

Cover of white goosefoot (CHEAL) is close to SORGHUM on the map and shares the characteristic that highest cover was observed in combinations with zero nitrogen dose, as can be observed in **Table 2**, too.

Maple-leaved goosefoot (CHEHY) could not be strongly connected with any combinations, as can also be observed in **Table 2**, when not combinations but single fertilizers are examined. On the other hand, the principal component analysis of another Hungarian experiment (Reisinger *et al*. 2005) shows that maple-leaved goosefoot is connected to P fertilizer stronger than white goosefoot and redroot pigweed.

A greater understanding of these relationships may allow the development of strategic fertilizer management strategies depending on the weed species existing in an agricultural crop.

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