Role of agrotechnical elements in sustainable wheat and maize production

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Abstract: In conventional crop production the yield increasing was based on the huge industrial chemical inputs and new genotypes of cereals. This extreme external input use could modified the resilience, adaptive capacity and sustainability of different crop models. The effects of different crop management factors were studied in long-term experiments on chernozem soil in Eastern Hungary. The fertilizer responses of wheat varieties depended on the crop year (6.5-8.2 t ha^{-1} in 2011-2014 years) and the genotype (in 2012 the difference was 2.7 t ha^{-1} among genotypes). The optimum N(+PK) dose varied between 30-150 kg ha^{-1} in different crop years. The N-doses over optimum caused NO_3-N accumulation in chernozem soil (from 32 mg kg^{-1} to 170 mg kg^{-1}). In sustainable maize production the fertilization resulted high yield surpluses in average (2.0-4.1 t ha^{-1}) and rainy (2.1-5.4 t ha^{-1}) crop year in our long-term experiment (in 1986-2014 years). The yield increasing of irrigation were agronomically effective only in dry crop years (3.3-4.9 t ha^{-1}) and they were very limited in average (1.2-1.3 t ha^{-1}) and rainy (0-0.2 t ha^{-1}) crop year (in 1986-2014 years) The optimum fertilization could improve WUE in maize production.

Keywords: crop rotation, fertilization, irrigation, WUE, NO_3-accumulation

Introduction

Significant yield increases of cereals (mainly wheat and maize) have been achieved from the 1970's years in the developed and partly in the developing countries. These yield increasements were based on the huge industrial, chemical inputs (fertilizers, pesticides, gasoline etc.) and new genotypes of cereals. This "industry-like" crop production resulted high yield and enormous harmful environmental effects and less agronomy and energy efficiency (Austin 1999, Pepó 2007, Olesen et al. 2011). Traditional cereal production uses a lot of external inputs to achieve high yields (Hole et al. 2005). Hungarian crop production is cereal-oriented one. Proportion of cereals (small grains and maize) takes about 70% of Hungarian arable land. In sustainable cereal production nutrient supply, fertilization is a key agrotechnical element (Jordan et al. 1997, Oehl et al. 2004, Keller et al. 2012), but the crop rotation, irrigation, plant density, weed control (Berzsenyi et al. 2000, Vad et al. 2007) have important role, too. The yield-losses and yield fluctuation of cereals caused by crop year (climate change) depended on soil conditions, the stress-tolerance of genotypes and the agrotechniques. According to literature (Shen et al. 1999, Pepó 2009) the yield decreases of cereals varied between 2-55%. Because of climate change the water saving crop management and water use efficiency are especially important in arable crop production. Graymore and Wallis (2010) built up a conceptual model of the factors impacting on water use of different users, including drivers and barriers to water saving.

The main aim of this study was to evaluate the long-term experimental data on chernozem soil in Eastern-Hungary to show the effects of ecological factors (crop year) and agrotechnical elements (fertilization, crop rotation, irrigation) and genotypes on the yields of winter wheat and maize. Our further aim was to show how can modify the applied input level the resilience and adaptive capacity of different cereal crop models and how we can keep the sustainability of cereal crop production.

Materials and methods

Our study was based on long-term experiments on chernozem soil in Eastern Hungary.

Location

The long-term experiments were set up in Látókép Experimental Station on calcorous chernozem soil in 1983 year. Geographical location is N 47°33' and 21°27'.

Experimental site

Soil type is chernozem which has nearly neutral

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pH (pH_{KCl} = 6.46). The original chemical traits of soil are as the following: humus content 2.76% (0-0.2 m upper soil layer), thickness of humus layer 0.8 m, AL-P_2O_5 content 130 mg kg^{-1}, AL-K_2O content 240 mg kg^{-1} of plowing layer). Chernozem soil has excellent water husbandry.

The long-term experimental site can be characterized by continental climatic conditions. The average yearly precipitation is 565 mm and average yearly mean temperature is 9.84 ^oC.

Treatments of long-term experiments

Fertilizer response testing of winter wheat genotypes experiment which includes 2 factors (i = fertilization, control and N = 30 kg ha^{-1}, P_2O_5 = 22.5 kg ha^{-1}, K_2O = 26.5 kg ha^{-1} and 2-, 3-, 4-, 5-folds of the basic dose; ii = genotypes [15-20 varieties]). The experimental design is split-split-plot with 4 replications. The plot-size is 10 m^2. (Long-term experiment 1 = LTE1)

Polyfactorial long-term experiment of cereal crop models which includes 3 factors (i = crop rotation: mono-, bi- and triculture, ii = fertilization: control and N = 60 kg ha^{-1}, P_2O_5 = 45 kg ha^{-1}, K_2O = 45 kg ha^{-1} and 2, 3, 4-folds, iii = water supply [rainfed and irrigated]). The experimental design is split-split-plot with 4 replications. The plot-size is 46 m^2. (Long-term experiment 2 = LTE2)

Measurements and observations in the long-term experiments

At the harvest the yields and seed moisture determined. In certain years we measured the soil NO_3-N, AL-soluble P_2O_5 and K_2O contents (in 0-3 m soil profile in every 0.2 soil layers) after harvest.

Statistical analyses of data

The experimental data analysed with SPSS 13.0 statistical software package.

Results and discussions

The basic element of sustainable cereal production is to select the suitable, adaptable genotypes into agroecological and agrotechnical conditions. The nutrient supply and fertilization have the key-role in the sustainable wheat production because on the one hand fertilization directly and indirectly modifies all other agrotechnical factors (crop protection etc.) and the other hand the over-optimum fertilization causes different harmful effects (NO_3-N accumulation in different soil layers etc.). Our long-term experimental results (LTE1) proved that weather conditions (mainly the rainfall quantity and its distribution) strongly modified the yields of winter wheat genotypes even on chernozem soil characterized by excellent water- and nutrient husbandry. In the average of wheat varieties and crop years the yield was 7508 kg ha^{-1} but the yields varied depending on the crop years (Table 1). The minimum yield was in 2013 (6514 kg ha^{-1})

Table 1. Fertilizer response of winter wheat genotypes in different crop years (Debrecen, chernozem soil, 2011-2014)

Variety	2011(N_{opt})	2012(N_{opt})	2013(N_{opt})	2014(N_{opt})	Average
GK Öthalom	6819 $_{(150)}$	6175 $_{(150)}$	5983 $_{(150)}$	8713 $_{(30)}$	6923
Pannonikus	8123 $_{(90)}$	8139 $_{(150)}$	6576 $_{(150)}$	7996 $_{(30)}$	7684
Euclide	9586 $_{(150)}$	8919 $_{(150)}$	7590 $_{(150)}$	-	8698
GK Csillag	-	7263 $_{(150)}$	6562 $_{(150)}$	8350 $_{(60)}$	7392
Bitop	-	6075 $_{(150)}$	6089 $_{(120)}$	6663 $_{(30)}$	6276
GK Békés	-	7917 $_{(150)}$	6281 $_{(120)}$	7915 $_{(30)}$	7371
Average	*8176*	*7415*	*6514*	*7927*	*7508*
Yield interval, t/ha	6.8-9.6	6.1-8.9	6.0-7.6	6.7-8.4	6.4-8.6
Min-Max, %	83-117	82-120	92-117	84-105	85-115
Interval of yield fluctuation, %	34	38	25	21	30
Interval of N_{opt} kg ha^{-1}	90-150	120-150	120-150	30-60	90-128
$LSD_{5\%}$	457	355	600	674	-

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and we got the maximum yield in 2011 (8176 kg ha^{-1}). The winter wheat genotypes could differently adapt to the crop year. According to our long-term experimental data we could state that the differences among the varieties were about 3 t ha^{-1} in the same agrotechnical conditions (in 2012 the yields varied between 6075-8919 kg ha^{-1}). The crop year (mainly the water supply during the vegetation period) can modify the optimum N+PK doses, too. In crop year characterized by average water supply the optimum N+PK doses varied between N=90-150 kg ha^{-1} +PK and in crop year after very mild winter the N_{opt} +PK dropped down to N=30-60 kg ha^{-1} +PK (because of very high mineralization of organic matter in the chernozem soil).

The winter wheat is one of the best fertilizer-responding field crops. Our long-term experimental data (LTE1) proved that the fertilization of wheat resulted good yield surpluses on chernozem soil characterized by excellent natural nutrient stock (*Table 2*). The yield surpluses of wheat varied between 940 kg ha^{-1} (2002/2003 crop year) and 4858 kg ha^{-1} (2012/2013 crop year). The yields of control treatment proved the excellent natural nutrient avaibility of chernozem soil (1816 kg ha^{-1} and 5897 kg ha^{-1}). The other meteorological parameters could modify the yield surplus of wheat genotypes (in 2010 extra rainfall caused high lodging and leaf-, stem- and ear infections, in 2013 the strong and long frosting period in March decreased the yields, in 2014 the very mild winter period accelerated the N-mineralization in chernozem soil).

The using of N-fertilization over optimum level can cause NO_3-N accumulation in different soil layer. Our long-term experimental data proved (LTE1) that N-fertilization exceeding the agroecological demand of winter wheat genotypes increased the NO_3-N accumulation zone in chernozem soil (*Table 3*), so this fertilization method could decrease the sustainability of wheat crop models. The usage of N-doses over the optimum level caused NO_3-N accumulation in chernozem soil. The NO_3-N content of soil increased (from 32 mg kg^{-1} to 170 mg kg^{-1} NO_3-N) and its accumulation zone moved down to the deeper soil layer (from 0.8-1.0 m to 1.0-2.5 m). So if we want to convert the

Table 2. Effect of crop year on the control and maximum yield of winter wheat (Debrecen, 1999-2014) (average of varieties)

Crop year	Control yield kg ha^{-1}	Maximum yield kg ha^{-1}	Yield-surplus kg ha^{-1}	Rainfall in veg. period (mm)	Rainfall deviation from 30 year average (mm)
1998/1999	4042	6598	2556	470.4	+69.5
1999/2000	4041	8296	4250	312.9	-88,0
2000/2001	3193	7226	4033	430.2	+29,3
2001/2002	4466	6555	2091	184.6	-216,3
2002/2003	3447	4387	940	279.3	-121,6
2003/2004	4713	8573	3860	376.5	-24,4
2004/2005	4539	8098	3559	410.4	+9,5
2005/2006	3949	7016	3067	476.5	+37,6
2006/25007	3402	6893	3491	208.6	-192.3
2007/2008	5138	7218	2080	484.9	+84.0
2008/2009	3775	7696	3921	329.8	-71.1
2009/2010	3618	5539	1921	630.5	+229.6
2010/2011	4023	8043	4020	340.9	-60.0
2011/2012	3906	7303	3397	320.7	-80.2
2012/2013	1816	6674	4858	480.2	+79.3
2013/2014	5897	8556	2659	284.0	-116.9

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Table 3. Effect of nitrogen fertilization on the NO_3-N content of chernozem soil in long-term experiment (Debrecen, 1988-2003)

Year	Maximum NO_3-N content (mg kg^{-1})	Width of NO_3-N accumulation zone (m)	Years from set up the long-term experiment
1988	32	0.8-1.0	5
1992	120	0.8-1.3	9
1996	150	1.0-1.6	13
1999	170	1.4-2.0	16
2001	270	1.2-2.4	18
2003	170	1.0-2.5	20

conventional cereal production based on huge industrial inputs (Austin 1999, Pepó 2007, Mayer et al. 2015) we have to use optimum genotype selection and optimum agrotechnical elements (focusing on fertilization).

Maize is a sensitive field crop to agroecological and agrotechnical factors. Our multifactorial long-term experimental data (LTE2) proved that the effects of fertilization were different depending on the crop rotation and the weather of crop year. In Eastern Hungary characterized by continental climate the precipitation quantity and its distribution are the decisive agroecological factors on chernozem soil. The effects of crop year were significant on the yields of maize in every crop rotation (*Table 4*). We obtained the strongest effect of crop year in monoculture, so sustainability needs diversified crop rotation. The efficiency of fertilization was modified by crop year and crop rotation. The yield surpluses of maize were low (891-1315 kg ha^{-1}) in dry crop years and they were much bigger in average (1998-4145 kg ha^{-1}) and in rainy crop years (2117-5399 kg ha^{-1}), respectively. The biggest fertilization effects were in monoculture and lowest ones were in triculture (*Table 4*) because of high control yields. So the appropriate crop rotation can reduce the N+PK fertilizer doses (in mono- N_{180} +PK, in bi- N_{120} +PK, in triculture N_{60} +PK) and can promote the sustainability in maize production.

Our long-term research data (LTE2) proved that the using optimum fertilizer doses (N+PK) can increase the water use efficiency (WUE = kg yield/1 mm rainfall in vegetation period) of maize both in dry and average crop years (*Table 5*). In different crop rotations the WUE of control varied between 9.5-23.7 kg mm^{-1} in dry and 20.8-30.6 kg/mm in average crop years, respectively. In optimum N+PK treatment the

Table 4. Effect of crop year, crop rotation and fertilization on the yield of maize in long-term experiment (Debrecen, chernozem soil, 1986-2014)

Crop rotation	Yield (kg ha^{-1}) Dry crop year 11 years (38%)		Average crop year 12 years (41%)		Rainy crop year 6 years (21%)	
Monoculture						
Control	3743 e	1315*	6397 e	4145*	7190 c	5399*
N_{opt} +PK	5058 d		10 542 bc		12 589 a	
Biculture						
Control	7279 bc	924*	9289 d	2825*	9963 b	2117*
N_{opt} +PK	8203 a		12 114 a		12 080 a	
Triculture						
Control	6708 c	891*	9451 cd	1998*	10 023 b	2355*
N_{opt} +PK	7599 ab		11 449 ab		12 378 a	

*yield surplus of fertilization (kg ha^{-1})

a, b, c, d, e Letters are significantly different at $P \leq 0.05$ level

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Table 5. Water use efficiency (WUE) of maize in different crop years (Debrecen, chernozem soil, non irrigated)

Crop rotation	Fertilizer treatment	Dry crop year	Average crop year
		yield kg/1 mm rainfall in vegetation period	
Monoculture	Control	9.5 d	20.8 d
	N_{opt} +PK	15.2 c	39.1 a
Biculture	Control	22.1 b	28.4 c
	N_{opt} +PK	27.2 ab	35.8 ab
Triculture	Control	23.7 ab	30.6 bc
	N_{opt} +PK	28.2 a	40.4 a

a, b, c, d Letters are significantly different at P ≤ 0.05 level

Table 6. Effect of crop year, crop rotation and irrigation on the yield of maize in long-term experiment (Debrecen, chernozem soil, N_{opt} +PK, 1986-2014)

Crop rotation / Water supply	Yield (kg ha^{-1})					
	Dry crop year 11 years (38%)		Average crop year 12 years (41%)		Rainy crop year 6 years (21%)	
Monoculture						
non irrigated	5039 d	4858*	10 536 d	1323*	11 662 c	-38*
irrigated	9897 b		11 859 bc		11 624 c	
Biculture						
non irrigated	8182 c	3341*	12 019 bc	1276*	11 723 bc	98*
irrigated	11 523 a		13 295 a		11 821 bc	
Triculture						
non irrigated	7619 c	3466*	11 547 c	1284*	12 071 ab	197*
irrigated	11 085 ab		12 831 ab		12 268 a	

*yield surplus of irrigation (kg ha^{-1})
a, b, c, d Letters are significantly different at P ≤ 0.05 level

WUE values were much higher (15.2-28.2 kg mm^{-1} and 35.8-40.4 kg mm^{-1}, respectively).

The most efficient agrotechnical element against drought is irrigation. The effect of irrigation depended on the meteorological situation of crop years (*Table 6*). During 29 years of our long-term experiment the proportion of crop years was the following: 38% dry, 41% average and 21% rainy crop year, respectively. The yield surpluses were fairly big in dry crop years to obtain good irrigation response of maize (3341-4858 kg ha^{-1}). In average and rainy crop years the yield surpluses of irrigation were very limited (1276-1323 kg ha^{-1} and -38-197 kg ha^{-1}, respectively).

In sustainable maize production fertilization, irrigation and crop rotation have decision role on the yields. The scientific findings of Berzsenyi et al. (2000) and Vad et al. (2007) showed the crop rotation, fertilization and irrigation have main effects on the yields of maize according to our long-term experimental results.

Long-term experiments with a range of different cropping systems, fertilization treatments, genotype testing are a central component of research to develop more sustainable agricultural systems including different crop models. Monitoring agricultural sustainability requires different indicators (Barrios and Sarte, 2008).

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