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YIELD AND NUTRIENT USE EFFICIENCY OF FIELD CROPS GROWN IN THE REGION OF SADIEVO, SOUTH BULGARIA

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Abstract

Fertilizer experiment in four field's crop rotation (wheat, barley, maize, and sunflower) was carried out in the region of Sadievo, Bulgaria, during the period 2009-2012. The aim of the research was to study the effect of fertilization on crop productivity and nutrient use efficiency (NUE) of the mentioned four field crops. The fertilizer treatments were: Control; N; P; K; NP; NK; PK; NPK. Agronomic Efficiency (AE), Partial nutrient balance (PNB) and Recovery efficiency (RE) were the indicators calculated for assessing the NUE. The fertilization was very effective practice – NPK treatment ensured 71% higher yields for maize, 64% for wheat, 60% for barley and 51% for sunflower in comparison with control, on average for 4 years period. In spite of the relatively good fertilization effect, AE data was lower than reported as typical levels for cereals crops which showed relatively low productivity of unit nutrient input. PNB values for N showed that removed nitrogen amounts were higher and the deficit was less pronounced in wheat. In maize and sunflower PNB values for N were high and showed a severe nitrogen balance deficit. PNB and RE values for P showed that the fertilization rates could be decreased, while PNB and RE for K indicated that for maintaining the soil K content, the fertilization with K was recommendable in spite of the relatively low agronomic efficiency.

Key words: *Nutrient use efficiency, NPK, wheat, barley, maize, sunflower.*

INTRODUCTION

One of the main crop management practices affecting field's crop yields is the application of mineral fertilizers. The nutrient which strongly affects yields is nitrogen (Lopez-Bellido et al., 2005; Kismányoky & Tóth, 2010; Boukef et al., 2013). In most of the cases unbalanced application and utilization of nitrogen, phosphorus and potassium fertilizers is a reason for low efficiency of fertilization (Romheld, 2006; Nikolova, 2010). The current nitrogen application strategies for field crops cultivation are extremely inefficient, with nitrogen efficiency ranging from 14% to 59% (Melaj et al., 2003; Loppez-Bellido et al., 2005). Baligar et al. (2001) summarizing results from different publications estimates that overall efficiency of applied fertilizers has been below 50% for N, less than 10% for P, and about 40% for K. The lower the level of soil fertility is, the higher the agronomic efficiency of applied phosphorus and potassium is (Fixen, 2009). One modern method for assessing the effectiveness of fertilization is by determinating of Nutrient Use Efficiency (NUE) indicators (Rao, 2007). These indicators represent the ability of plants to translate the uptaken nutrients into economic yield-grains (Delogu et al., 1998). The aim of the efficient use of nutrients is to increase productivity of crops, to minimize nutrient losses and to maintain fertility of the soil (Mikkelsen et al., 2012; Fixen et al., 2015). Grain yield and NUE depend on many factors such as the soil, climate conditions, environment, grown cultivars etc. (Delogu et al., 1998; Noulas et al., 2010; Zhu et al., 2011). Asplund et al. (2016) made connection between the amount of chlorophyll in the plants leafs, its correlation with N content and NUE indicators in the pot and field experiments with more than 50 spring and winter varieties of wheat. NUE can also be expressed through agronomic, physiological and economic indicators (Rao, 2007). The optimization of fertilization of crops should be determined by conducting precise local experiments. The aim of the present research was to study the effect of fertilization on crop productivity of field crops grown in the region of Sadievo, South Bulgaria, and to estimate some NUE indicators.

MATERIALS AND METHODS

Omission plot trials in four field crop rotation - wheat, maize, barley, and sunflower was conducted in region of Sadievo, Bulgaria (42°31'38.1"N 26°05'39.3"E), during the period 2009-2012. Soil type was clayed Eutric Vertisols with clay content of 56.13%. The trial included eight fertilizing variants with nutrient addition and omission: control; N; P; K; NP; NK; PK; NPK. Fertilization rates based on soil diagnostic are presented on Table 1.

Table 1. Applied fertilizer rates for every crop kg ha^{-1}

Nutrients	Wheat	Barley	Maize	Sunflower
N	100	80	140	80
P_2O	120	120	120	120
K_2O	80	80	80	80

The used fertilizers in the experiment were ammonium nitrate (N - 33.4%), triple superphosphate (P_2O_5 - 46%), and potassium chloride (K_2O - 60%). The obtained data was processed for calculating of three agronomic indexes indicating the nutrient use efficiency:

AE - Agronomic Efficiency of applied nutrient (kg kg^{-1}) = ($yield_{nutrient}$ - $yield_{control}$)/nutrient rate; PNB - Partial nutrient balance (kg kg^{-1}) = removed nutrient/fertilizing rate;

RE - Recovery efficiency of applied nutrient (kg kg^{-1}) = (removed nutrient at fertilizing treatment - removed nutrient at control)/fertilizing rate.

RESULTS AND DISCUSSIONS

The fertilization was an effective practice at all grown crops (Figure 1 and Table 2). The most effective nutrient was nitrogen. Single application of nitrogen increased yields from winter cereal crops (wheat and barley) with 41% on average. The increase of the yields for maize and sunflower was 36 %. Double nutrient applications - NP and NK also ensured formation of higher yields especially at wheat, barley and maize.

The average yield increase of these crops was from 45 to 62% higher than the control. The increase in the same treatments was lower at sunflower, 26-28%, more than in the control treatment. Single addition of P and K and their double combination (PK), because of N omission had weak effect on yield, especially at sunflower. The application of the three nutrients (balanced NPK variant) had the best results but the increased yields at wheat, barley and maize was comparatively small in comparison with NP and NK variants. NPK fertilization demonstrates the highest yield increase at sunflower - 51% in comparison with control variant. The effect of other fertilizing treatments on the yield of sunflower was comparatively small (Table 2).

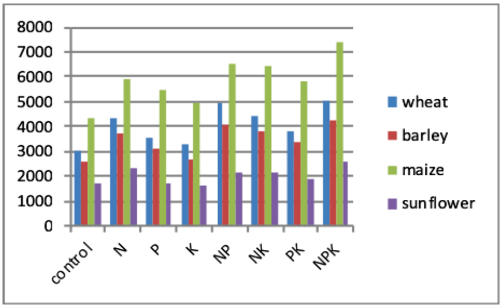

Figure 1. Yields of field crops (average for period 2009-2012) (kg ha^{-1})

Table 2. Relative yields of field crops (average for period 2009-2012) (%)

Variants	Wheat	Barley	Maize	Sunflower
control	100	100	100	100
N	141.0	141.9	136.1	136.3
P	116.3	117.7	127.2	103.4
K	106.9	101.8	114.1	98.1
NP	161.4	156.3	150.6	129.0
NK	145.6	144.8	149.8	126.3
PK	123.7	129.6	134.7	111.6
NPK	163.8	160.6	171.3	151.2

AE is index representing the ability of the crops to increase yield in response to applied fertilizers. According to Fixen et al. (2015) and Liu et al. (2011) AE_N at wheat ranges from 10-30 kg kg^{-1}. The data for wheat grown in Sadievo region were in the same range for all variants with nitrogen application - from 12 to 14 kg kg^{-1} (Table 3). These figures were close to the lower value for this indicator according to the above-mentioned authors. Delogu et al. (1998), Baligar et al. (2001) and Zhu et al. (2011) found out that the values for AE_N for wheat decreased with increasing of the nitrogen rate. According to the same authors, the index is also dependent on the time of application of nitrogen as pre–sowing or top–dressing.

Another factor which influences the AE indicator is grown cultivar (Noulas et al., 2010). Agronomic efficiency (AE) of phosphorus and potassium application was less than AE for nitrogen fertilizers. The PNB_N indicator was the lowest at variant with single N addition, 0.96 kg kg^{-1}. It was increased at double nutrient addition (NK and NP). The highest value for this indicator was determined at balanced nutrient combination (NPK). The values for double and triple fertilizer combinations were above 1, which indicated that the wheat had removed higher amount of nitrogen from the soil than the amount of the element applied with the fertilizers. This suggests negative N balance, better manifested at the most productive NPK treatment. Nitrogen fertilizer rates for wheat grown in Sadievo region should be increased when balanced with P and K crop fertilization is foreseen. The published data about PNB_N index by Zhu et al. (2011) showed considerable variation of the index depending on the rate of N fertilizers and time of their application. The data for PNB in Sadievo indicated that applied amounts of P and K fertilizers cover the crop needs of both elements (Table 3) and exceeded the P and K uptakes from the soil. The data for PNB_P (0.2-0.3 kg kg^{-1}) indicated strongly positive P balance which showed that the P rate could be reduced in order to increase AE_P. K balance was also positive but the higher PNB_K data (0.6-0.9 kg kg^{-1}) indicated that at most productive practice of balanced NPK fertilization, K application is recommendable in order to maintain the soil fertility.

The RE indicator represents the actual amount of removed nitrogen by crop from the applied fertilizers (in comparison with the control treatment). According to Mosier et al. (2001) and Fixen et al. (2015), the RE values of nitrogen for wheat range between 0.4-0.7 kg kg^{-1}. The highest values for RE_N in our trials were found for NP and NPK variants. The RE_P and RE_K were low for all treatments. Only RE_K from NPK variant showed higher value - 0.34 kg kg^{-1}.

Table 3. Nutrient use efficiency for wheat (average for the period 2009-2012)

variant	AE kg kg^{-1}			PNB kg kg^{-1}			RE kg kg^{-1}		
	N	P	K	N	P	K	N	P	K
N	13			0.96			0.33		
P		6			0.2			0.04	
K			4			0.6			0.01
NP	14	6		1.20	0.3		0.48	0.11	
NK	12		4	1.07		0.8	0.32		0.19
PK		5	5		0.2	0.7		0.04	0.06
NPK	12	5	3	1.26	0.3	0.9	0.48	0.10	0.34

Fixen et al. (2015), determined values in the range 15-30 kg kg^{-1} as typical AE_N index for barley. The same like at wheat tendency for AE_N indicator was found out by Delogu et al. (1998). The values for AE decreased with increasing of nitrogen rate. AE_N index for barley in the region of Sadievo was below this range (Table 4). This suggest for low efficiency of applied nitrogen fertilizers in the region. The lowest AE_N index was found at NPK treatment - 10 kg kg^{-1}. Delogu et al (1998) found that AE mean values of barley and wheat were similar in experiment in Italy and ranged between 8.7 and 9.2 kg kg^{-1}. The data for region of Sadievo about AE_N was also similar for both crops but were higher in comparison with the cited study (Tables 3 and 4) and ranged between 10 and 14 kg kg^{-1}. This suggests that both species respond equally to N fertilization.

The data for PNB_N from the similar experiment conducted in the region of Pomorie, Bulgaria, were in the range between 0.86-0.94 (Manolov et al., 2018). The results from Sadievo were almost the same in all treatments (1.14–1.17 kg kg^{-1}) but higher than in the Pomorie region. They were also higher compared to the typical values for this index according to Fixen et al. (2015) (0.7-0.9 kg kg^{-1}). This indicated that applied fertilizer rate can not cover the needs of nitrogen for grown barley in the region of Sadievo and should be increased. Considerable part of applied P was not uptaken by crop

(PNB_P - 0.2 kg kg^{-1}). This should lead to increasing of soil phosphorus reserves. A bigger part of the applied K with fertilizers was absorbed by crop (PNB_P - 0.6-0.9 kg kg^{-1}). The results indicated that part of applied K remains in the soil and increased its potassium reserves. The barley adsorbed less than the half of applied N rate (RE_N - in the range 0.35-0.44 kg kg^{-1}), while the adsorbed P from fertilizers was very low (0.03-0.09 kg kg^{-1}). The RE_K for single application of the element was very low 0.07 kg kg^{-1}. The combine application of K with N and P increased considerably the data for RE_K. The highest amount of absorbed K from fertilizers was found at variant NPK (0.31 kg kg^{-1})

Table 4. Nutrient use efficiency for barley (average for the period 2009-2012)

Variant	AE kg kg^{-1}			PNB kg kg^{-1}			RE kg kg^{-1}		
	N	P	K	N	P	K	N	P	K
N	14			1.17			0.44		
P		5			0.2			0.03	
K			1			0.6			0.07
NP	13	4		1.16	0.3		0.38	0.10	
NK	14		4	1.14		0.8	0.39		0.28
PK		6	6		0.2	0.7		0.09	0.20
NPK	10	4	2	1.17	0.2	0.9	0.35	0.09	0.31

The AE_N data for maize was similar at different treatments (9-11 kg kg^{-1}) (Table 5) and was lower than typical ones for this crop (15-30 kg kg^{-1}) (Fixen et al., 2015). Fixen et al. (2015) indicated values ≥ 7 kg kg^{-1} as typical for AEp for maize. Walsh et al. (2012) found out decreasing of NUE_N with the increasing of the nitrogen rates at maize. Such values of 8 kg kg^{-1} for experiment in Sadievo were found at single P addition and NPK variants. The AE_K was also the highest at NPK treatment reaching 11 kg kg^{-1}.

The PNB_N values for the trial in Sadievo exceeded 1 for all treatments and were higher than the typical values (0.7-0.9 kg kg^{-1}) (Fixen et al., 2015). Therefore, the quantity of applied nitrogen was less than the quantity of N removed by maize. There were no big differences between the results for PNB_P (Table 5). The results were very low which means that considerable part of the applied P remained in the soil and increased its phosphorus reserves. Because of high K removal by maize, a large amount of potassium was taken from the soil reserves (PNB_K was in the range 1.4-2.0 kg kg^{-1}). This means that fertilizer K rates should be increased in order to maintain soil potassium reserves at optimal level.

For the maize, grown in the region of Sadievo, the values of RE for the three nutrients were highest at the NPK treatment. At the treatments with single nutrient addition or nutrient omission the RE values were much lower. The optimal values in NPK variant could be explained by the higher yield when balanced nutrition is ensured. The higher biomass formation and respective higher nutrient uptake lead to better utilization of applied nutrients.

Table 5. Nutrient use efficiency for maize (average for the period 2009-2012)

Variant	AE kg kg^{-1}			PNB kg kg^{-1}			RE kg kg^{-1}		
	N	P	K	N	P	K	N	P	K
N	11			1.05			0.35		
P		8			0.3			0.12	
K			9			1.5			0.29
NP	9	3		1.24	0.4		0.39	0.17	
NK	11		3	1.22		2.0	0.43		0.49
PK		4	3		0.4	1.4		0.13	0.23
NPK	11	8	11	1.31	0.5	1.6	0.92	0.30	0.46

AE for N, P and K for sunflower was comparatively low (Table 6). The lowest AE values were registered for P. For the three nutrients AE was the highest at the balanced NPK treatment, reaching 8 kg kg^{-1} for N, 5 kg kg^{-1} for K and 4 kg kg^{-1} for P. Similar was the agronomic efficiency at the treatment with P omission (NK) and could be concluded that at the conditions of Sadievo phosphorus was the nutrient with lower efficiency for sunflower.

Table 6. Nutrient use efficiency for sunflower (average for the period 2009-2012)

Variant	AE kg kg^{-1}			PNB kg kg^{-1}			RE kg kg^{-1}		
	N	P	K	N	P	K	N	P	K
N	8			1.29			0.42		
P		1			0.2			0.02	
K			1			1.0			0.02
NP	5	4		1.29	0.3		0.37	0.09	
NK	7		6	1.28		1.4	0.48		0.43
PK		0	3		0.2	1.1		0.08	0.15
NPK	8	3	5	1.49	0.3	1.8	0.57	0.12	0.84

PNB for N and K were much higher than 1 for all variants, but low in comparison with data received for the region of Pomorie (Manolov et al. 2018) (Table 6). The results showed that the crop uptakes much more N and K from the soil than was applied with fertilizers. This indicated that the fertilization rates for both nutrients should be increased. PNB_P kept the tendency for low values found at the other crops included in the experiment. Considerable amount of applied P by fertilizers remained in the soil. This was confirmed by the values for the indicator RE_P which were very low especially for treatment P (Table 6). RE_N varies slightly between the treatments and was in the range 0.37-0.57. RE_K varies significantly (0.02-0.84) due to the big yield differences depending on addition or omission of nitrogen. For the three nutrients highest RE values were recorded at NPK treatment indicating that balanced fertilization led to formation of the highest yield, respectively the highest removal of nutrients and better utilization of applied nutrients with fertilizers.

CONCLUSIONS

The fertilization of all studied field crops in the region of Sadievo was a very effective practice. The highest efficiency of fertilization was registered at maize, followed by winter cereals (wheat and barley) and sunflower. The nitrogen was the main limiting nutrients in the region of Sadievo. The balanced NPK fertilization demonstrated the highest efficiency. Similar to NPK effect was obtained under NP and NK treatments for wheat and barley. The values for Agronomic Efficiency showed relatively low efficiency of unit nutrient input in spite of the relatively good fertilization effect. Partial Nutrient Balance and Recovery Efficiency for phosphorus indicated that the fertilization rates could be decreased in order to increase the Agronomic efficiency. Both indices for potassium showed that for maintaining the soil K content, fertilization with K is recommended despite the relatively low agronomic efficiency of the element.

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