Planning Winter Wheat Yields Based on the Environment and Nutrient Management

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Results from field studies show that optimization of plant nutrition with N, P and K is an important factor in improving both yield and quality of winter wheat grown in Southern Russia. High yield goal-based NPK application resulted in grain yield increases of 87 to 93%. Two methods for calculating nutrient rates worked well for a yield goal of 4.0 t/ha. Yield goals of 5.0 t/ha and 6.0 t/ha were not attained, but a comparison of the approaches to yield planning suggests a slight advantage for one method over the other.

Setting crop yield goals comprises an understanding of a complex set of interrelated measures. Timely and precise consideration of these measures helps both the achievement of goals for crops yield and quality as well as goals for long-term soil fertility and environmental protection (Esaulko et al., 2013). The goal of crop yield planning is to determine the site-specific yield potential for each crop or variety (Esaulko and Ustimenko, 2012). These data could be obtained through fertilizer response trials in the field; however, crop characteristics obtained in variety trials can also be used (Esaulko et al., 2012; Ustimenko, 2013).

Field experiments at the Stavropol State Agrarian University (SSAU) Research Farm were conducted during 2010-2012 adopting existing regional approaches to setting winter wheat yield goals. Winter wheat variety "Zustrich" was selected, which is a medium maturity (vegetation period 273 to 282 days), medium height variety with good lodging resistance characterized by high environmental plasticity, drought and frost tolerance. It is also a high gluten, high protein variety (i.e., gluten 27 to 28%, protein 12.0 to 13.5%).

Field experiments were conducted on a deep-leached chernozem (Luvic Chernozem) of clay loam texture. Soil pH was close to neutral (average pH_{KCl} = 6.7), soil OM was medium (5.1 to 5.6%), and the soil had medium levels of available P (average 22 ppm P_2O_5) and K (240 to 260 ppm K_2O) extracted with 1% $(NH_4)_2CO_3$ solution. Winter wheat was preceded in the crop rotation by field pea. Field experiments were conducted within a RCB design with three replications. Whole plot size and harvest area were 40 m^2 (10 m × 4 m) and 22 m^2, respectively.

Weather conditions during three experimental years were characterized by nonuniform distribution of precipitation (**Table 1**). Annual precipitation was below the long-term average with the exception of the 2009-2010 agricultural year. Experimental years had elevated temperatures with an annual temperature 1.1 to 1.4°C above the long-term average. The most favorable weather conditions for winter wheat growth and development were observed in 2010-2011. Total precipitation during August, 2010 to July, 2011 was 7% below the long-term average; however, its uniform distribution contributed to optimal water supply to plants and hence the highest grain production. The average air temperature was found to be 10.6°C in 2010-2011, which exceeded the long-term average by 1.4°C. Extremely unfavorable weather conditions were observed in 2011-2012. Nonuniform distribution of rainfall during spring-summer 2012 negatively affected winter wheat production.

Abbreviations and Notes: N = nitrogen; P = phosphorus; K = potassium; KCl = potassium chloride; MAP = monoammonium phosphate; OM = organic matter; ppm = parts per million.

Nutrient Rate Calculations

Two methods were used to calculate nutrient rates based on winter wheat grain yield goals of 4.0, 5.0 and 6.0 t/ha. According to the 1st approach developed by SSAU (Ageev and Podkolzin, 2006), P and K rates were calculated as follows:

$$\text{Nutrient rate } (P_2O_5 \text{ and } K_2O \text{ rate, kg/ha}) = \frac{R - RK_s}{K_f}\ 100,$$

where:

R = nutrient removal in wheat grain plus straw (P_2O_5 and K_2O, kg/ha) at the planned yield goal;

K_s = coefficient showing P and K recovery from soil reserves by wheat crop at the planned yield goal depending on available P and K levels in the soil (0.47 to 0.66 for P and 0.58 to 0.70 for K);

K_f = coefficient showing apparent crop recovery efficiency of applied nutrient (40% and 70% for P and K, respectively).

Nitrogen rates were calculated using the following updated formula:

$$\text{N rate (kg/ha)} = \frac{R(N) - R_{(P2O5)}K_{s\,(P2O5)}K}{K_f}\ 100, \text{ where:}$$

K = N removal in wheat grain plus straw/P_2O_5 removal in wheat grain plus straw at the planned yield goal;

Table 1. Distribution of precipitation (mm) during the experimental years according to the Stavropol Weather Station.

	Months												
Years	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Total
2009-2010	85	70	13	68	21	53	36	68	25	94	22	70	625
2010-2011	5	67	83	19	24	19	17	46	52	87	107	54	580
2011-2012	75	11	10	20	20	37	17	37	13	38	96	83	457
Long-term average	54	43	46	41	32	27	34	53	70	90	80	53	623

Table 2. Effect of fertilizer application on yield components of winter wheat (three-year average) in Stavropol.

Treatment	Method of nutrient rate calculation	Yield goal, t/ha	Number of productive tillers per m^2 (NPT)	Number of kernels per spike	Kernel weight per spike, g	1000 kernel weight, g
Control	-	-	373	23	0.98	34.0
$N_{60}P_{60}K_{30}$*	-	-	394	25	0.97	35.2
$N_{60}P_{34}K_{34}$	1	4.0	402	27	1.04	36.4
$N_{68}P_{44}K_{24}$	2		404	25	1.00	36.1
$N_{105}P_{60}K_{60}$	1	5.0	403	26	1.04	36.7
$N_{90}P_{67}K_{40}$	2		425	28	1.03	37.1
$N_{126}P_{80}K_{72}$	1	6.0	432	28	0.99	37.2
$N_{110}P_{82}K_{51}$	2		431	30	1.07	37.5

Note: $N_{60}P_{60}K_{30}$ is a blanket fertilizer recommendation. The 1st and the 2nd approach to nutrient rate calculation were developed by V.V. Ageev (Ageev and Podkolzin, 2006) and by L.N. Petrova et al. (1987), respectively.

K_f = coefficient showing apparent crop recovery efficiency of applied N (70%).

The 2nd approach was developed by researchers from Stavropol Research Institute of Agriculture and Stavropol State Centre for Agrochemical Service. Nutrient rates were calculated as follows (Petrova et al., 1987):

Nutrient rate (N, P_2O_5, and K_2O, kg/ha) =YRKc, where:

Y = winter wheat yield goal, t/ha;
R = nutrient (N, P_2O_5, and K_2O) removal in wheat grain plus straw, kg/t grain;
Kc = coefficient showing nutrient use to removal for wheat grain plus straw (0.49 to 0.52 for N, 1.10 to 1.36 for P, and 0.30 to 0.43 for K depending on the planned yield goal).

Moreover, a zero fertilizer treatment (control) and recommended blanket rates for the agro-ecological zone ($N_{60}P_{60}K_{30}$) were also included into the experimental scheme. Fertilizer applications included basal rates of K applied as KCl before tillage and P fertilizer as MAP at planting. Nitrogen fertilizer was topdressed in early spring as ammonium nitrate.

Results

Three-year averages for yield components of winter wheat are presented in **Table 2**. Results indicate that number of productive tillers (NPT) varied most widely compared to other growth parameters depending upon the level of plant nutrition. NPT improved from 373 to 432 tillers/m^2 due to increasing fertilizer use. Different fertilizer combinations increased NPT by 21 to 59 tillers/m^2 compared to the non-fertilized control. The highest values (431 to 432 tillers/m^2) were obtained in treatments receiving $N_{126}P_{80}K_{72}$ and $N_{110}P_{82}K_{51}$ nutrient rates for the highest yield goal of 6.0 t/ha.

Number of kernels per spike also increased due to fertilizer application and the difference with the control reached 2 to 7 kernels/spike. The highest number of 30 kernels/spike was formed in the treatment receiving $N_{110}P_{82}K_{51}$. Kernel weight per spike also increased through all fertilizer treatments except the recommended blanket rates ($N_{60}P_{60}K_{30}$). The difference with control varied from 1 to 9% depending on fertilizer rates. Similar to the number of kernels the highest kernel weight per spike (1.07 g) was obtained in the treatment receiving $N_{110}P_{82}K_{51}$. Fertilizer combinations positively affected 1,000 kernel weight. Recommended blanket rates ($N_{60}P_{60}K_{30}$) had the lowest effect on the above-mentioned parameter resulting in only 4% increase compared to 6 to 10% in other fertilizer treatments. The heaviest kernels (37.5 g per 1,000 kernels) were formed with the fertilizer combination of $N_{110}P_{82}K_{51}$.

Fertilizers significantly increased winter wheat grain yield in our study because of considerable improvement of the yield components. Grain yield increase over the control ranged from 0.76 to 2.80 t/ha in 2009-2010, from 1.03 to 2.90 t/ha in 2010-2011, and from 0.97 to 2.28 t/ha in 2011-2012 depending upon the fertilizer combination (**Table 3**). Hence, plant nutrition with N, P and K is highly important for winter wheat production on leached chernozems of the region resulting in yield increases of up to 87 to 93%.

Optimization of winter wheat nutrition based on a yield goal of 4.0 t/ha indicates that both methods for calculating nutrient rates allow for quite precise yield planning. A higher grain yield of 4.17 t/ha (three-year average) was obtained in the treatment receiving $N_{68}P_{44}K_{24}$ (i.e., when we used the 2nd method for calculating nutrient rates). Recommended blanket rates ($N_{60}P_{60}K_{30}$) gave a similar yield of 4.16 t/ha. The 1st method for determining nutrient rates resulted in lower productivity of 3.90 t/ha ($N_{60}P_{34}K_{34}$).

Both methods for calculating nutrient rates were also quite reliable when we set a yield goal of 5.0 t/ha. There was a small difference from the average attainable yield that was slightly lower than this planned yield goal. Marginally better yield planning was observed when we used the 1st approach and got

Table 3. Effect of fertilizer application on grain yield and quality of winter wheat in Stavropol.

Treatment	Method of nutrient rate calculation	Yield goal, t/ha	------- Grain yield, t/ha ------- 2009-2010	2010-2011	2011-2012	Average	Gluten, %	GDI	Protein, %
Control	-	-	3.06	3.12	2.63	2.94	17.1	80	10.5
$N_{60}P_{60}K_{30}$	-	-	4.59	4.30	3.60	4.16	22.3	73	11.3
$N_{60}P_{34}K_{34}$	1	4.0	3.82	4.15	3.72	3.90	23.7	75	11.0
$N_{68}P_{44}K_{24}$	2		4.18	4.39	3.93	4.17	24.3	72	11.3
$N_{105}P_{60}K_{60}$	1	5.0	5.22	4.63	4.34	4.73	25.5	72	11.5
$N_{90}P_{67}K_{40}$	2		4.63	5.17	4.21	4.67	24.9	73	11.1
$N_{126}P_{80}K_{72}$	1	6.0	5.86	6.02	4.91	5.60	27.0	75	12.5
$N_{110}P_{82}K_{51}$	2		5.68	5.80	4.61	5.36	26.3	73	12.7
$LSD_{0.05}$	-	-	0.37	0.27	0.32				

Note: Three-year averages are given for grain quality parameters. GDI = Gluten Deformation Index.

Experimental plots of winter wheat during 2009 season (4th December).

an average yield of 4.73 t/ha ($N_{105}P_{60}K_{60}$).

However, we revealed considerable differences between attainable yield and the highest yield goal of 6.0 t/ha. The 1st approach to determining nutrient rates allowed an average grain yield of 5.60 t/ha ($N_{126}P_{80}K_{72}$). Grain yield was lower with the 2nd method ($N_{110}P_{82}K_{51}$) and averaged 5.36 t/ha giving an 11% difference from the yield goal. Nevertheless, we didn't reveal significant differences between the above-mentioned treatments. It is important to indicate that attainable yield was much closer to the yield goal of 6.0 t/ha in the year 2010-2011, which had the most favorable weather conditions.

The improvement of winter wheat grain quality has exceptional importance in the region. Data shown in **Table 3** indicate that all nutrient combinations resulted in higher gluten content in grain (by 5.2 to 9.9%) compared to control. The highest gluten content (26.3 to 27.0%) was obtained in treatments receiving high fertilizer rates ($N_{126}P_{80}K_{72}$ and $N_{110}P_{82}K_{51}$). Fertilizer application also contributed to high gluten quality as indicated by the Gluten Deformation Index (GDI). GDI ranged from 72 to 75 units in fertilizer treatments. Significant improvements of grain protein content by 2.0 to 2.2% were obtained only at high fertilizer rates ($N_{126}P_{80}K_{72}$ and $N_{110}P_{82}K_{51}$).

Recommended nutrient combinations for the yield goal of 6.0 t/ha were the most profitable in our study. The Return on Investment (ROI) for these two treatments receiving $N_{110}P_{82}K_{51}$ and $N_{126}P_{80}K_{72}$ was as high as 125% and 131%, respectively (**Table 4**).

Table 4. Profitability analysis of winter wheat production (three-year average) in Stavropol.

Index	Control	Treatment $N_{126}P_{80}K_{72}$	Treatment $N_{110}P_{82}K_{51}$
Grain price, Ruble/t	8,200	9,000	9,000
Gross revenue, Ruble/ha	24,108	50,400	48,240
Production cost, Ruble/ha	13,250	22,410	20,880
Production cost, Ruble/t	4,506	4,001	3,895
Net income, Ruble/ha	10,858	27,990	27,360
ROI, %	82	125	131

Note: US$1 = 32.87 Russian Rubles.

Summary

Optimization of plant nutrition with N, P and K is very important in improving both yield and quality of winter wheat grown on leached chernozems in Southern Russia. Both methods for calculating nutrient rates attained the planned yield goal of 4.0 t/ha. Yield goals of 5.0 t/ha and 6.0 t/ha were not attained taking into consideration the average winter wheat production for three years. More precise yield planning could be achieved when nutrient rates are calculated using the 1st method developed by SSAU. BC

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