

Role of Crop Nutrition in Narrowing the Yield Gap for Spring Wheat in Siberia

By G. Gamzikov and V. Nosov

Mineral fertilizers and other agro-inputs are important for achieving high and stable yields of spring wheat, the principle field crop in Siberia. This article reviews the attainable yield of spring wheat by the major soil-climatic zones through the region. The authors characterize the present status of fertilizer consumption in Siberia and, based on minimum nutrient requirements of crops, give a short-term estimate of fertilizer consumption in the region.



Siberia is located in the Asian part of Russia, occupying an area of about 10 million square kilometers (M km²). Arable farming and animal husbandry are concentrated in the southern part of Siberia, with more than 56 M ha of agricultural lands. Siberia has about 23.5 M ha of arable land, representing about one-fifth of the total arable land area in Russia. Spring cereals such as wheat, barley, oats, and millet, as well as buckwheat, pulses, sunflower, potato, and vegetables are traditional crops in Siberia. Winter cereals include rye and triticale. Spring rapeseed, soybean, and sugar beet are promising crops giving high yields in this region. Cereals are grown on 70% of cropped area. Spring wheat dominates the cereal acreage (75 to 80%). However, the average grain yield of spring wheat in Siberia over the 5-year period of 2004 to 2008 was only about 1.3 t/ha.

The grain belt of Siberia, comprising several soil-climatic zones, is characterized by diversity in annual rainfall (230 to 550 mm), the sum of active temperatures above 10 °C (1,400 to 2,800 growing degree days), and length of vegetation or frost-free period...100 to 140 days. In the forest zone, arable soils are represented by soddy-podzolic and grey forest soils occupying 17% of land in Siberia. Podzolized, leached, and common chernozems, and also meadow chernozem soils (63%) are spread throughout the forest-steppe zone. Southern chernozems and chestnut soils (14%) are dominant in the steppe zone. Soil fertility parameters affect crop production potential in the various soil zones of Siberia. A recent agrochemical soil survey indicated that organic matter (humus) content in Siberian soils can be very low to low (<4.0%), medium to high (4.1 to 8.0%), and high to very high (>8.1%), with about one-third of the monitored arable area under each group (Figure 1). Acid arable soils, which need liming for optimal yield, occupy about 2 M ha in the region.

Nitrate-N (NO₃-N), is the major source of soil N for plant nutrition (Gamzikov, 1981). Siberian soils have a high potential to accumulate NO₃-N during the fallow season, after late summer tillage following perennial grasses, pulses, and annual grasses. Spring wheat grown after fallow and the above-mentioned crops has no requirement for additional application of N fertilizer. Two-thirds of the area sowed to field crops, following other preceding crops, has low soil N status and requires annual application of N fertilizer. According to routine soil analyses, slightly more than half of Siberian arable soils have high and very high content of available P, about one-third of soils test medium to high, and only 15% of soils are



Spring wheat is grown on millions of hectares of land in Siberia, but yields in recent years have averaged only about 1.3 t/ha.

low to very low in available P (Figure 1). The lowest content of P (low and very low classes) is observed in soddy-podzolic soils (57%), and in southern chernozems and chestnut soils (40%). Most soils (79%) have high to very high contents of available K (Figure 1). Taking into consideration the status of soil nutrients in Siberian soils, annual recommendations for cultivated crops include N on 16 M ha, P fertilizer on more than 10 M ha, and K fertilizer on 5 M ha.

Soil-climatic conditions in three natural zones of Siberia are favorable for obtaining high yields of spring wheat when recommended crop management practices are followed (Table 1). The role mineral fertilizers play in crop production is most important in the forest zone. Without plant protection and application of mineral fertilizer, spring wheat grain yields fail to exceed 1.0 t/ha. But intensive agro-technologies can produce 2.6 to 4.5 t/ha. Unstable rainfall, low soil NO₃-N, and low available P in some soil provinces limit yield formation on dark grey forest soils, podzolized, leached and common chernozems, and meadow chernozem soils in the forest-steppe zone. Here, the average grain yield for spring wheat does not exceed 1.5 t/ha under extensive systems of crop production, and only 2.0

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; ppm = parts per million.

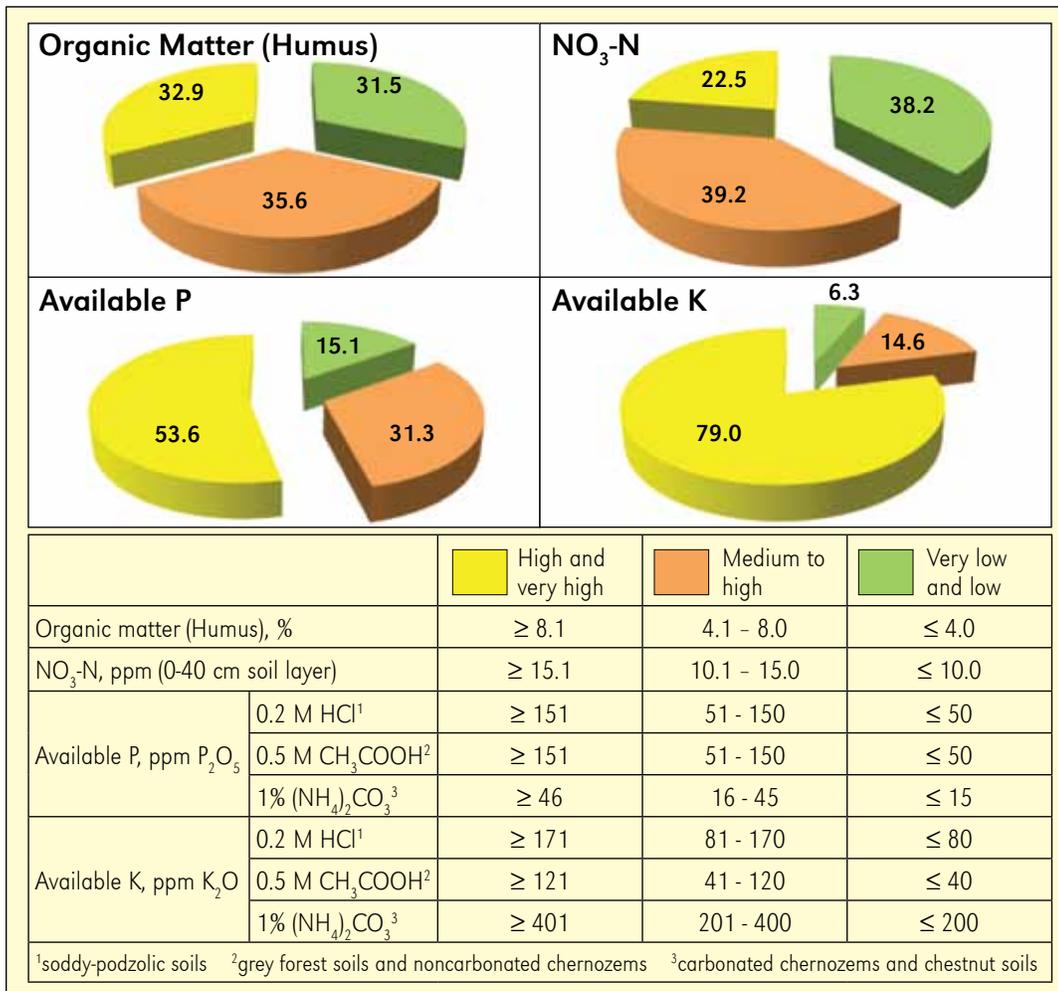


Figure 1. Distribution (%) of arable soils in Siberia in fertility classes according to status of soil organic matter, NO₃-N, and available P and K. (Source: Russian Res. Inst. of Agrochemistry, 2005.)

Table 1. Possible grain yields (t/ha) of spring wheat depending on soil-climatic conditions and systems of agriculture in Siberia (Gamzikov et al., 2008).

Natural zone	--- Climatic and soil limitations ¹ ---			--- System of agriculture ⁵ ---		
	Solar radiation ²	Rainfall ³	Soil fertility ⁴	Extensive	Ordinary	Intensive
Forest	4.0-5.8	3.8-5.0	0.6-1.5	0.5-1.0	0.7-1.6	2.6-4.5
Forest-steppe	5.0-7.2	1.7-4.0	1.2-2.4	0.8-1.5	1.0-1.8	2.2-4.0
Steppe	6.0-8.6	0.8-2.2	1.0-1.6	0.4-1.0	0.8-1.6	1.5-2.2
Distribution of agricultural enterprises, %				35-40	50-60	10-15

¹Possible yields when climate and soil factors are not limiting.
²Possible yield range with application of fertilizer (and lime if required) plus optimal rainfall.
³Possible yield range with application of fertilizer (and lime if required).
⁴Possible yield range without fertilizer or lime.
⁵Extensive: without fertilizers and plant protection.
 Ordinary: 10 to 20 kg/ha N+P₂O₅+K₂O in seed row and plant protection in selected fields.
 Intensive system: recommended crop management technologies; use of all agro-inputs.

Table 2. Long-term average effect of mineral fertilizer use on grain yield of spring wheat on Siberian soils (Gamzikov et al., 2008).

Soil	Yield without fertilizers, t/ha	---Yield increase with fertilizers ¹ , t/ha ---			
		N	P	NP	NPK
Soddy-podzolic soil	1.06	0.46	0.32	0.57	0.79
Grey forest soil	1.57	0.41	0.30	0.60	0.67
Chernozem	1.68	0.33	0.22	0.49	0.52
Chestnut soil	1.14	0.16	0.18	0.31	0.31

¹40 to 60 kg/ha each of N, P₂O₅, and/or K₂O.
 These findings summarize all field research in Siberia.

t/ha in years with especially favorable hydrothermal conditions. Attainable grain yields with recommended, intensive agro-technologies range between 2.2 and 4.0 t/ha. In the steppe zone (in view of the considerable moisture deficit in these southern chernozems and chestnut soils, and their low capacity to mobilize N), the average grain yield for spring wheat under an extensive system of crop production is usually under 1.0 t/ha. Nevertheless, it is possible to improve yield to 1.5 to 2.2 t/ha in this zone if all recommended agro-technologies are applied.

The application of mineral and organic fertilizers in combination with other agro-inputs and recommended agro-technologies allows growers to realize the existing yield potential in every soil-climatic zone while eliminating, or at least alleviating, the negative impact of common natural and anthropogenic factors. **Table 2** summarizes the average grain yield increase for spring wheat due to application of combinations of fertilizer nutrients in Siberia. The highest effect of fertilizers on grain yield can be observed on soddy-podzolic and grey forest soils – the agronomic efficiency of applied fertilizer nutrients is generally in a range of 4 to 9 kg high quality grain per kg of nutrients (N+P₂O₅+K₂O).

The appropriate tillage method in combination with the recommended use of fertilizers and other agro-inputs allows growers to better realize their yield potential (**Figure 2**). Accumulated research data and growers' practice indicate that conservation tillage technologies coupled with recommended application of all agro-inputs, including mineral fertilizers, generates the highest grain yields (1.5 times higher), decreases the cost of grain production (by 17%), and thus increases profits (by 25%).

Despite this, mineral fertilizer use in Siberian agriculture has declined by more than 10 times over the last 20 years (**Table 3**). Nutrient balance calculations for Siberia clearly indicate a negative balance for all three nutrients (**Table 4**). In fact, total fertilizer inputs account for only 11% of crop nutrient removal in recent years. The short-term forecast (up to 2015) for increased mineral fertilizer consumption gives hope for a gradual alleviation of nutrient deficiencies and a considerable gain in spring wheat yields. Currently, Siberian agriculture has to rely on crop management

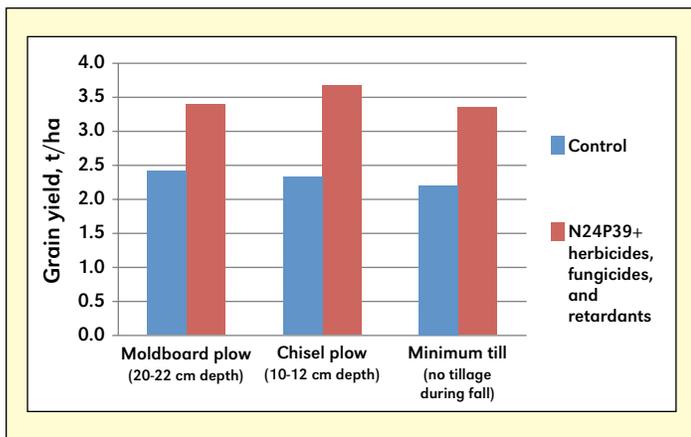


Figure 2. Effect of fall tillage method on grain yield of spring wheat grown after fallow in fallow-wheat-maize-wheat-barley crop rotation on leached chernozem; mean 1988-2000 (Kholmov and Yushkevich, 2006).

Available P and K content (0.5 M CH_3COOH) – 80 to 95 ppm P_2O_5 and 400 to 500 ppm K_2O . Fertilizer rates: 24 kg/ha N and 39 kg/ha P_2O_5 .

systems that exploit indigenous soil fertility because of its limited use of mineral fertilizers and other inputs. Including fallow (the best predecessor for wheat in all natural zones of Siberia) in the rotation is the most commonly used practice. The fallow season in 3 to 4 year rotations allows for high accumulation of moisture reserves (160 to 220 mm within a 100 cm soil depth) and $\text{NO}_3\text{-N}$ (100 to 120 kg/ha within a 40 cm soil depth). Fallow also decreases the number of weed seeds per square meter (to 30 to 35).

Specific soil-climatic conditions in Siberia (i.e., deep and prolonged soil freezing during the winter season, uneven distribution of rainfall through the vegetative period, and periodical droughts) increase the role of crop variety and its interaction with the crop management system. Spring wheat breeding in Siberia is done by 11 research institutions and agrarian universities. The State Register of Russia was expanded over the last 30 years (1977 to 2007) to include 63 new soft and 9 new durum varieties of spring wheat (Ruts and Kashevarov, 2008). It is noteworthy that Siberian varieties at present occupy 95% of the total area under spring wheat in the region. Breeding for higher yields of soft and durum spring wheat has progressed by 50% and 35%, respectively. Grain quality parameters have improved by 14 to 25% and 9 to 20%, respectively, during these last 30 years (Gamzikov, 1997; Ruts and Kashevarov, 2008). Modern spring wheat varieties have high yield potential (3.5 to 7.0 t/ha) and high grain quality (1,000 grain weight of 40 to 50 g, test weight of 780 to 820 g/l, protein content of 15 to 18%, gluten content of 32 to 40%). Most varieties registered for production over the last 8 years have complex immunity to pathogens and resistance to leaf rust, powdery mildew, and loose smut. Siberian research on the genetics of mineral nutrition of spring wheat has resulted in fundamentally new information about the genetic control of uptake and utilization of macronutrients and micronutrients in plants (Gamzikova, 2008). Specific genomes, chromosomes, genes, and cytoplasm controlling uptake and utilization of nutrients in wheat plants

Table 3. Average annual fertilizer consumption ($\text{N}+\text{P}_2\text{O}_5+\text{K}_2\text{O}$) in Siberian agriculture, '000 ton.

Region	1986-1990	2001-2005	2006-2009	2015-2020 (outlook)
Western Siberia	832	53.7	70.9	260
Eastern Siberia	470	45.3	46.9	135
Siberia Total	1,302	99.0	117.8	395

Table 4. Average nutrient balance (kg/ha/year) in Siberian agriculture (2006-2009).

Nutrient	Crop removal	Fertilizer input			Balance	Input/Removal, %
		Mineral	Organic	Total		
N	30.7	2.5	1.2	3.7	-27.0	12
P_2O_5	10.1	0.9	0.6	1.5	-8.6	15
K_2O	24.4	0.3	1.7	2.0	-22.4	8
Total	65.2	3.7	3.5	7.2	-58.0	11

have been identified. Concepts and methodologies have been designed for breeding nutrient-efficient genotypes that are more adept at using soil and applied nutrients compared to modern varieties.

In the near-term, spring wheat will continue to be the dominant crop in Siberian agriculture. High and stable yields of spring wheat and also high grain quality in growers' fields will depend on adoption of best management practices recommended by researchers. This may be achieved with the corresponding development of grain export capabilities from Siberia and attractive grain prices at the grower's gate. 

Prof. Dr. Gamzikov is Head, Laboratory of Actual Problems of Experimental Agrochemistry, Novosibirsk State Agrarian University; e-mail: gamolgen@rambler.ru. He is Academician of the Russian Academy of Agricultural Sciences. Dr. Nosov is Director, IPNI Southern and Eastern Russia Region, located in Moscow; e-mail: vnosov@ipni.net.



Dr. Gamzikov, left, and Dr. Nosov

References

- Agrochemical characteristics of agricultural soils of Russian Federation. 2005. Russian Res. Inst. of Agrochemistry, Moscow. 183 p. (In Russian).
- Gamzikov, G.P. 1981. Nitrogen in agriculture of Western Siberia. Nauka, Moscow. 268 p. (In Russian).
- Gamzikov, G.P., I.F. Khramtsov, and V.K. Kalichkin. 2008. Proc. Annual Meeting of the Russian Academy of Agri. Sciences, Siberian Branch. Novosibirsk, pp. 58-78. (In Russian).
- Kholmov, V.G. and L.V. Yushkevich. 2006. Intensification and resource conservation in agriculture of Western Siberia forest-steppe. Omsk State Agrarian University, Omsk. 396 p. (In Russian).
- Ruts, R.I. and N.I. Kashevarov. 2008. Proc. Annual Meeting of the Russian Academy of Agri. Sciences, Siberian Branch. Novosibirsk, pp. 26-47. (In Russian).
- Gamzikov, G.P. 1997. *In Wheat: Prospects for Global Improvement* (H.J. Braun et al., eds.). Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 55-59.
- Gamzikova, O.I. 2008. Etudes on physiology, agrochemistry and genetics of plant mineral nutrition. Agros, Novosibirsk. 372 p. (In Russian).