The Efficiency of Potassium Fertilizer Use in Western Siberia

By Vladimir N. Yakimenko and Vladimir V. Nosov

A brief review shows that application of K fertilizer to cereal crops grown on soils of Western Siberia can contribute to 20 to 30% yield increases. Field experiments conducted in 'cereals-fodder crop' systems suggest a trend towards higher yields due to K application in both first spring wheat or spring barley crops. A significant yield response to K was obtained for second spring wheat and forage crops of maize or oat-pea mixes. Significant increases in carrot and potato yields were observed within the 'vegetable-potato' cropping system even at the lowest K rates.

Recent statistics highlight widespread nutrient depletion within the extensive farming systems of the Siberian Federal District of Russia. Agricultural enterprises only applied about 7 kg N, 2 kg P_2O_5 and less than 1 kg K_2O per hectare of sown area in 2011 (ROSSTAT, 2012). Farmers widely rely on a fallow year to gather plant-available N reserves, which is generated from nitrate (NO_3-N) accumulation through soil OM mineralization. However, this does have negative implications for soil OM reserves and their ability to maintain nutrient supplying power year after year. Crops also rely heavily on a continuous tapping of any available soil P and K reserve. Considering the need to intensify crop production in the Western-Siberian region, while recognizing the regional economic realities, the issues related to the most effective and efficient use of mineral fertilizers, including K fertilizers, seem very important.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; CEC = cation exchange capacity; OM = organic matter; ppm = parts per million; ppm K_2O x 0.83 = ppm K.

Critical Field Trials

Nowadays, there are practically no field experiments in Western Siberia studying the use of K fertilizer. However, our brief review summarizes results obtained from the most recent critical research conducted in the region (**Table 1**). The highest K response in spring wheat was found on soddy-podzolic soils (Umbric Albeluvisol) because these soils have low plant-available K. The relative grain yield increase due to K ranged between 6 to 28%. The effect of K fertilizer on crop yield was much higher on coarse-textured soddy-podzolic soils, which have the lowest level of plant-available K. Application of K on grey forest soils and dark grey forest soils (Humic Luvisol) increased spring wheat yields by 2 to 11%. On leached chernozems (Luvic Chernozem), K fertilization contributed as much as 16% to grain yields; however, some field experiments conducted on these soils did not show any advantage to K use in cereal crops. Yield of maize grown for green forage on chernozem soils increased by 8 to 10% due to K application. On chernozemic soil, crop response to applied K is highly dependant on the level of plant-available K. Exchangeable K content in chernozems of Western Siberia can be very high at 600 ppm K_2O and above and a response to applied K is unlikely under such conditions, especially in cereal crops.

Long-term studies conducted on

Table 1. Summarized results of field experiments studied the efficiency of K fertilizer use in Western Siberia. Adapted from Yakimenko, 2003.

Soil type/subtype	Crop†	Yield, t/ha 0	NP	+K	Yield increase due to K, %	Reference
Soddy-podzolic (Umbric Albeluvisol)	Wheat	0.41	1.01	1.29	28	Kopotilov, 1980
		1.43	1.85	2.19	18	
		1.30	1.94	2.30	9	Sinyavskiy, 1989;
		1.53	1.88	2.00	6	Titova, 2000
Grey forest (Humic Luvisol)	Wheat	0.65	1.23	1.37	11	Karchevskiy, 1991
Dark Gray Forest (Humic Luvisol)	Wheat	1.50	2.02	2.06	2	Zakharov, 1982
Leached chernozem (Luvic Chernozem)	Oat	1.28	2.06	2.34	14	Zhukova, 1974
	Barley	1.48	1.94	2.25	16	
	Wheat	1.20	1.60	1.86	16	
	Wheat	2.82	3.19	3.13	-2	Guselnikov, 1973
	Forage maize	29.5	39.8	42.8	8	Rusakova, 1981
	Barley	3.09	3.61	3.85	7	
	Wheat	2.70	3.64	3.43	-6	
	Wheat	2.66	2.96	3.09	4	Khurchakova and Ostrovlyanchik, 1988
	White cabbage	47.0	68.9	70.8	3	Almazov and Kholuyako, 1983
	Carrot	41.2	50.6	53.9	7	
	Potato	28.2	32.7	34.1	4	
	Tomato	41.6	46.5	52.8	14	Almazov and Kholuyako, 1994
Southern chernozem (Calcic Chernozem)	Forage maize	21.8	30.2	33.1	10	Altunin et al., 1983

†Spring wheat and spring barley are indicated; yield of green forage is shown for maize.

Table 2. Soil-test interpretation classes for exchangeable K (ppm K_2O) in the forest-steppe zone of Western Siberia. Yakimenko, 2009.

	- - - - - - - - - - - - - Soil texture - - - - - - - - - - - - -		
Soil K test level	Light loam	Medium loam	Heavy loam
Low	< 100	< 150	< 200
Unstable	100 - 150	150 - 200	200 - 250
Optimal	150 - 200	200 - 250	250 -300
High	> 200	> 250	> 300

Content of particles <10 μm in light, medium and heavy loams is 20 to 30, 30 to 40, and 40 to 50%, respectively.

grey forest soils revealed that exchangeable K is a better indicator of soil K status compared to routinely measured available K (extracted with acetic acid [CH_3COOH] solution). Exchangeable K better reflects soil K depletion, and also build up, of soil fertility resulting from any K application (Yakimenko, 2009). In addition to the improved soil test interpretation classes for routinely measured available K in the forest-steppe zone; soil test interpretation classes for exchangeable K were also developed in consideration of soil textural classes (**Table 2**).

It is important to note that the majority of fertilizer experiments above have been short-term field trials with spring wheat and vegetable crop rotations (3 to 4 years) without long-term omission of K and hence without considerable soil K depletion. Moreover, crop yield levels were low in many of these experiments resulting in relatively low quantities of nutrients required for crop growth and development. Earlier reviews of fertilizer experiments conducted in forest and forest-steppe zones of Western Siberia indicate that K fertilizer use becomes necessary only when the yield level of cereal crops is higher than 3 t/ha (Gamzikov et al., 1989). A single season field experiment with spring wheat conducted in Omsk Oblast in 2011 on a leached chernozem with very high exchangeable K came to the same conclusion (unpublished IPNI data). There is a relative lack of regional experimental data on the efficiency of K fertilizer within high K demanding crops.

Cropping System Studies

Field experiments conducted from 1988 to 2005 help to answer many important questions regarding the efficiency of K fertilizer use in common cropping systems of Western Siberia. On previously uncultivated grey forest soil with medium loam texture at the surface, an initial exchangeable K level of 145 ppm K_2O, OM content of 4.9%, and CEC of 21 cmol/kg soil (Yakimenko, 2006), field experiments were simultaneously conducted in two experimental areas with different cropping patterns: 1) cereals and fodder crops, and 2) vegetables and potato. Three cycles of the following crop rotation were run at the first experimental area: spring wheat–spring wheat–spring barley–oat/pea (green forage mixture). Spring wheat was then cultivated during two years and maize for silage was grown in the subsequent years. Three cycles of crop rotation with vegetables and potato were similarly run at the second experimental area: white cabbage–tomato–onion–carrot. Then, potato was grown in monoculture till the end of experiment. Field experiments included the following treatments: 1) zero fertilizer (control); 2) NP; 3) NPK_1; 4) NPK_2; 5) NPK_3; 6) NPK_4.

An advantage of residual K during the cropping season of cereals may be taken in Western Siberia if value-to-cost ratios for K fertilizer use are not favorable.

Table 3. Fertilizer rates (kg N, P_2O_5 and K_2O/ha) in field experiments conducted on grey forest soil. Yakimenko, 2003.

Cropping pattern	Crop	N	P	K_1	K_2	K_3	K_4
Cereals and fodder crops	1st spring wheat	90	60	30	-	90	-
	2nd spring wheat	90	60	30	-	90	-
	Spring barley	120	60	39	-	117	-
	Oat + pea	120	60	36	-	108	-
	Maize	180	90	75	-	225	-
Vegetables and potato	White cabbage	200	140	111	222	333	444
	Tomato	120	120	47	94	141	188
	Onion	55	23	25	50	75	100
	Carrot	126	78	64	128	192	256
	Potato	180	60	81	162	243	324

Rates of N and P fertilizers were calculated based on a 100% replenishment of nutrient removal in high yielding crops and four levels of K were applied to replenish K removal by 25, 50, 75, and 100%, respectively. Fertilizer rates for each crop grown under two cropping systems are given in **Table 3**. Fertilizers were applied in spring before sowing or planting of seedlings as ammonium nitrate, triple superphosphate, and potassium chloride (KCl).

The long-term average yield data for the 'cereals-fodder crops' system reveal a trend towards higher yields within the 1st spring wheat and spring barley crops as a result of K fertilization (**Table 4**). A significant yield response in the 2nd wheat crop was obtained when the highest K rate was applied (90 kg K_2O/ha). The highest K rates (108 and 225 kg K_2O/ha) also resulted in a significant increase in green forage yield of both the oat-pea forage mixture and maize.

The experimental data obtained under the 'vegetable-potato' system found a significant yield increase for these high K demanding crops (potato, carrot) even under the lowest K application rates (64 and 81 kg K_2O/ha). Significant yield increases in cabbage, tomato and onion were only obtained with the highest K rates, but practically all K rates provided

Table 4. Crop yields (t/ha) in field experiments conducted on grey forest soil (1988-2005 average). Yakimenko, 2006.

Cropping pattern	Crop†	0	NP	$+K_1$	$+K_2$	$+K_3$	$+K_4$	$LSD_{0.05}$
Cereals and fodder crops	1st spring wheat	2.79	3.14	3.26	-	3.32	-	0.35
	2nd spring wheat	2.38	2.66	2.77	-	2.90	-	0.21
	Spring barley	3.49	4.02	4.25	-	4.52	-	0.65
	Oat + pea mixture	21.0	23.6	24.6	-	26.2	-	2.5
	Forage maize	43.5	49.8	60.6	-	67.6	-	10.9
Vegetables and potato	White cabbage	85.0	106.1	110.8	113.0	115.6	116.9	10.5
	Tomato	35.0	49.4	54.1	56.1	57.2	59.9	6.9
	Onion	16.6	17.6	19.6	21.1	21.7	20.1	3.8
	Carrot	59.6	57.4	68.6	71.7	73.8	77.1	6.7
	Potato	14.4	14.9	26.3	34.6	35.4	36.0	8.0

†Yield of green forage for oat-pea forage mixture and maize, and bulb yield for onion are shown.

Potato tuber yield increased by 1.8 to 2.4 times as a result of K applied at the four rates studied.

evidence towards higher vegetable crop yields with their use. The highest yield response to K fertilizer was found in potato. Potato tuber yield increased by 1.8 to 2.4 times as a result of K applied at the four rates studied. Forage maize was the second most K responsive crop as green forage yield was improved by 1.4 times under the highest K rate of 225 kg K_2O/ha. Carrot also responded well to fertilizer K. Yield of carrot roots was increased by 1.3 times at the highest K rate of 256 kg K_2O/ha.

The lowest rates of K fertilizer applied under the 'cereals-fodder crops' system (30 to 75 kg K_2O/ha) gave agronomic efficiencies for K (AE_K) values of 4.0, 3.7 and 5.9 kg grain/kg K_2O in 1st spring wheat, 2nd spring wheat and spring barley, respectively. Similarly, values for AE_K in the oat-pea mixture and maize were 28 and 144 kg green forage/kg K_2O. Respective AE_K values under the 'vegetable-potato' system at the lowest rates of K input (25 to 111 kg K_2O/ha) were 42, 100, 80, 175, and 141 kg production/kg K_2O in cabbage, tomato, onion, carrot, and potato. The inclusion of K certainly generated the most profitable return when applied to most K demanding crops such as vegetables, potato and forage maize because these crops provided the highest yield increase. It is more interesting to assess the current profitability of K input to cereal crops because of the large area involved. We estimate that K fertilizer use in spring wheat (3rd grade soft wheat: gluten 23 to 28%) and spring barley (fodder grain) could be profitable in 2012 with a AE_K higher than 2.4 to 2.5 kg grain/kg K_2O excluding the costs of fertilizer delivery to the farm, fertilizer application and additional harvesting and drying for the added grain yield. Our estimates indicate that K fertilizer use in cereal crops grown on grey forest soils of Western Siberia is quite profitable and the maximum economic response can be achieved in barley as compared to wheat.

Conclusions

When growers make decisions on K application it is necessary to consider the level of soil exchangeable K, expected crop yield, and hence the crop's need for additional K. Fertilizer distribution in Western Siberia is not yet well developed and regional farm gate prices for wheat may be not as attractive for growers because of existing logistical problems. Thus it is quite possible that value-to-cost ratios for K fertilizer use in wheat would be unfavorable. In such cases, it is reasonable to apply K to the most K demanding crops within the crop rotation and take advantage of any residual K during the spring wheat cropping season. BC

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References

Gamzikov, G.P., V.B. Ilyin, V.M. Nazaryuk et al. 1989. Agrochemical parameters of soils and efficiency of fertilizers. Nauka, Siberian Branch, Novosibirsk. 254 p. (In Russian).

ROSSTAT. 2012. http://www.gks.ru

Yakimenko, V.N. 2003. Potassium in soils of Western Siberia agrocoenoses: PostDoc Dissertation. Novosibirsk. 306 p. (In Russian).

Yakimenko, V.N. 2006. Agrochemistry, 5: 3-11. (In Russian).

Yakimenko, V.N. 2009. Soil Fertility, 4 (49): 8-10. (In Russian).