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Original paper

POTATO TUBER YIELD AND QUALITY UNDER DIFFERENT POTASSIUM APPLICATION RATES AND FORMS IN WEST SIBERIA

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Potato cultivars have different strategies for dealing with potassium (K) deficiency in soil, and their response to different forms and rates of K fertilisation may vary because of differences in soil K availability. This study was performed to evaluate the effect of K fertilisation rates (0, 30, 60, 90, 120 and 150 kg K/ha) on tuber yield and quality (dry matter, starch, sugar and ascorbic acid content, taste) of two potato cultivars (Roco and Rosara) grown in the microplot field experiment on Luvisol in the forest-steppe zone in southern West Siberia, Russia (NL 54.422106, EL 83.160257). The tuber yield of both potato cultivars increased with increase in K application rate up to 2.1 and 2.9 kg/m^2 for Roco and Rosara, respectively. Sugar content, averaging 3.5%, was mostly determined by cultivar; however, in both cultivars it tended to decrease with increasing K application rate. The application of K fertiliser in the form of sulphate as compared to chloride increased dry matter content from 22.4 to 23.8% and ascorbic acid content from 13.2 to 14.6 mg/100 g fresh mass. Starch content of potato tubers averaged 59.7 ± 4.8% over all K fertilisation variants, with cultivar responses being different. Potassium application rate did not affect Roco tubers' taste, while improving Rosara tubers' taste under moderate application rates. The results underscore the importance to adjust fertiliser recommendations concerning potassium application rates and source on the basis of biological requirements and intended utilization of individual potato cultivars.

Key words: potato *Solanum tuberosum* L., long-term potassium fertilisation, microplot field experiment, Luvisol, ascorbic acid, starch, tuber dry matter

Globally potato is the third most important crop, and one of the major staple crops in Russia where potato production reached 31,501,354 tons in 2014 (FAO 2014). As potatoes are very well suited for human modern diet (Haase 2008), attention to its agronomy, breeding etc. will hardly cease. Recently potato production received significant attention of Russian policy-makers, resulting in establishing new potato breeding and research centers, as tailoring potato varieties or products to match the population nutritional needs is of major importance (Andre *et al.* 2014), and there is significant source of untapped adaptive potential in the extant natural populations of *Solanum tuberosum* L. (Hardigan *et al.* 2017).

The quality of crop yield is important for human diet with many health benefits, especially for technical crops like potato: such quality attributes as dry matter, starch and sugar contents are usually of primary concern and often rather strictly regulated.

Potato yields and tuber quality depend on a number of factors, such as soil and climatic conditions, agricultural techniques, biological and cultivar specifics, etc. Rational use of mineral fertilisers, ensuring 30–50% yield increase of good quality while preserving or even increasing soil fertility, is one of the important factors for sustainable and efficient functioning of agricultural ecosystems.

Potato tuber quality and yields are primarily determined by cultivar peculiarities. Lately zoning of

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potato cultivars throughout Russia and their subsequent production has been largely determined by cultivar yielding potential and disease resistance, with tuber quality receiving much less attention. As a result, highly productive feed or technical potato cultivars of poor culinary quality and sensory properties such as taste, flavour, texture, etc., have become prevalent in the country.

Crop biological peculiarities as well as its cultivar potential can be modified by many factors, including mineral nutrition and mineral fertilisation in particular. Since potato synthesizes a lot of carbohydrates, the crop needs plenty of nutrients.

Potassium (K) is well known for its importance for the growth and development of potato plants, and especially for tuber sensory quality as it is known to participate in starch biochemistry. Much research in various regions of Russia and other countries has been devoted to studying the effect of type, rates and forms of fertilisers on potato tuber yields and quality (Rhue *et al.* 1986; Davenport & Bentley 2001; Ewais *et al.* 2010). Most studies found that bigger yields correlated negatively with tuber quality, that mineral fertilisation should be carefully balanced, and that chloride-free fertilisers may be more beneficial. However, different effects of fertiliser rates and forms on potato tuber quality were also reported. Such results may be attributed to differences in climate, soils and agricultural technologies between the regions with experimental sites. Recently, with emergence of new cultivars and involvement of new areas into potato production, potassium regime optimization have been receiving more attention (Kumar *et al.* 2005). In West Siberia the studies of the effect of K fertiliser forms and rates on potato yield and quality have been few and therefore such studies are still quite urgent, especially under changing climatic conditions (IPCC 2013). Alongside the latter, low and often unbalanced fertiliser use in the region also contributes to increasing actuality of such research.

The aim of our work was to study the effect of different forms and rates of potassium fertiliser on potato tuber yield and quality of two cultivars in the long-term microplot field experiment in the forest-steppe zone of West Siberia.

MATERIAL AND METHODS

Location of the experiment and its layout

The experimental site is located in the forest-steppe zone of West Siberia (NL 54.42211, EL 83.16026). Originally the soil was grey wooded loamy soil developed on loess-like carbonaceous loam; such soils are quite common in the forest-steppe zone of West Siberia and represent one of the major soil types in the region. According to WRB (IUSS Working Group 2014), the soil is classified as Haplic Luvisol. The Experimental Station of the Institute of Soil Science and Agrochemistry (Siberian Branch of the Russian Academy of Sciences, Novosibirsk, Russia) was launched there in 1971 to conduct various field experiments. The long-term field experiment, described here, was started in 1988. Wheat was grown until 2000, and then potato has been grown. The results obtained on the soil can be extrapolated for other genetically similar soils of the region.

The experiment was setup with the following variants: no fertilisers (control variant), mineral NP fertiliser (100 kg of N and 60 kg of P per hectare (NP control), and 5 variants with potassium addition: NPK1, NPK2, NPK3, NPK4 and NPK5, where K1…K5 represent K fertiliser rates of 30, 60, 90, 120 and 150 kg/ha of potassium, respectively. The N, P and K4 fertiliser rates were calculated in such a way as to compensate for the output of the respective elements with anticipated 20 t/ha of tuber yield, taking into account non-marketable phytomass production as well. Mineral fertilisers were added every year in spring before planting. Nitrogen was added as ammonium nitrate, phosphorus was added as double superphosphate, and potassium was added in half of the experimental plots as potassium chloride and in the other half as potassium sulphate. The experiment was replicated four times. The plots were planted with Roco potato cultivar, but in 2016 early Rosara cultivar was also grown for the purposes of this study, namely comparing the effect of potassium fertiliser rates and forms on tuber chemical and sensory qualities. To ensure no effect of seed tubers on the results of the experiment, we used high quality seed tubers having biological, morphological and consumer properties which are characteristic for a given cultivar. Briefly, seed tubers of the Elite 3 and Elite 4 classes of about the same mass (*ca.* 60 g), disease-free and otherwise healthy were used in all experimental plots. Tubers for quality analyses and sensory testing were collected in 2016. Both cultivars (Table 1) are included in the State Crop Register of Russia and recommended for production in the West-Siberian region.

T a b l e 1

Characteristics of potato cultivars

Cultivar	Registered since	Origin of seed tubers	Maturity	Skin color	Flesh color	Utilization
Roco	2002	Russia	Mid early	Red	Creamy	Table
Rosara	1996	Russia	Early	Red	Yellow	Universal

Soil analyses

Prior to the experiment setup soil properties were determined. Briefly, soil organic carbon content was determined by estimating the loss of soil aliquot mass during ignition at 500°C (Wang *et al.* 2011); soil organic nitrogen content was determined by Kjeldahl technique; total soil phosphorus after perchloric acid digestion (O'Halloran & Cade-Menum 2008); total potassium by atomic emission spectrography. Exchangeable cations content, soil reaction and exchangeable acidity were measured according to Hendershot *et al.* (2008), while granulometric composition was assessed by pipetting (Kroetsch & Wang 2008). The soil contained 4.8% of organic carbon and 0.22% of organic nitrogen, 30.8% of physical clay, 0.15% of total and 18 mg/100 g o.d. soil of labile phosphorus; 1.5% of total and 12 mg/100 g o.d. soil of labile potassium; with pH (water) of 7.3 and cation exchange capacity of 21.5 cmol/kg o.d. soil.

Tuber analyses

After harvesting, yield, dry matter, starch, total sugar, ascorbic acid and taste of tubers were assessed. Dry matter content was determined in chopped composite samples from each plot by drying the whole samples in the oven at 80°C until constant weight was achieved. The starch and total soluble sugar content of samples was determined with the anthrone reagent and expressed on the dry matter basis. Ascorbic acid was measured by standard iodine titration technique. Tuber taste was scored (Thybo *et al.* 2006) on a scale of 5.

The obtained data were subjected to analysis of variance using *Statistica v. 6.1* (StatSoft Inc., USA).

RESULTS AND DISCUSSION

Tuber yield

Averaged over all variants, tuber yield was 1.7±0.7 kg/m^2 (fresh mass), with marked difference between the cultivars as Roco yielded 1.4±0.5, while Rosara yielded 2.0±0.7 kg/m^2 ($P \leq 0.001$). The yields were similar to those reported for the same cultivars grown in the European part of the country (Lebedeva & Nikitishen 2014). Statistical analysis (ANOVA) showed that the rate of K application was by far the leading factor for potato tuber yield variance in our experiment (Table 2), with cultivar biology being the second most important factor.

The source of K fertiliser slightly affected Roco tuber yield, which was 15% higher under KCl fertilisation (Table 3), and had no effect on Rosara (Figure 1). This result is somewhat surprising as in our study sulphur as potassium sulphate was added at the rates ranging 12–62 kg S/ha, i.e. the rates shown earlier to increase potato yield (Chettri 2002; Sharma *et al.* 2011; Barczak *et al.* 2013), with some researchers, however, reporting decrease in potato yield already at 60 kg S/ha (Singh *et al.* 2016). Tuber yield reduction by chloride was shown to be cultivar- and soil-dependent (van Loon & van der Berg 2003), being more pronounced in the sandy loam soil (similar to the one in our study) but not on the heavy clay soil. In the latter study chloride was applied at the rate of 400 kg Cl/ha, i.e. at much higher rate than in our experiment, where variant K5 was equivalent to 136 kg Cl/ha. No effect of K fertiliser source, i.e. sulphate *vs.* chloride, was also reported earlier for the rates comparable to ours (Kumar *et al.* 2007), as well as for the much higher rates (Stanley & Jewell 1989). Thus the effect of potassium source on potato tuber yield seems to be resultant from the interplay of at least several factors, with cultivar, rate and soil being the leading ones.

As for K fertilisation rate, Roco plants started to increase tuber yield from the K2 plot (Table 4), i.e. with 60 kg K/ha added, while Rosara increased tuber production by 44% already in K1 plot (Table 5), i.e. 30 kg K/ha.

In our experiment we found more yielding cultivar to be more responsive to potassium fertilisation rate and not sensitive to its source.

Tuber dry matter content

The DM content of potato tubers, produced in our experiment, averaged 23.1 ± 1.8% over all the variants. The K fertiliser rate was found to be the major factor in the DM content variance (Table 1). There was a gradual increase in DM content with K fertilisation rate: Roco tubers had 10% more DM content in variants K4 and K5 as compared to NP variant (Table 3), while Rosara tubers increased their DM content already in K3 variant.

Much higher rates of K fertilisation, ranging 90–730 kg K/ha, were shown earlier to reduce tuber DM content (Ferreira *et al.* 2016).

The chemistry of K fertiliser was found to affect DM content in potato tubers of both cultivars (Table 2, Figure 1); averaged over them, K_2SO_4 addition as compared with KCl, increased DM content from 22.4 to 23.8%. Other researchers showed earlier that K-sulphate gave significantly higher DM values than K-chloride (Toolangi 1995; Barczak *et al.* 2013); yet the others found no significant effect of S application on the DM content in potato tubers (Sharma *et al.* 2011).

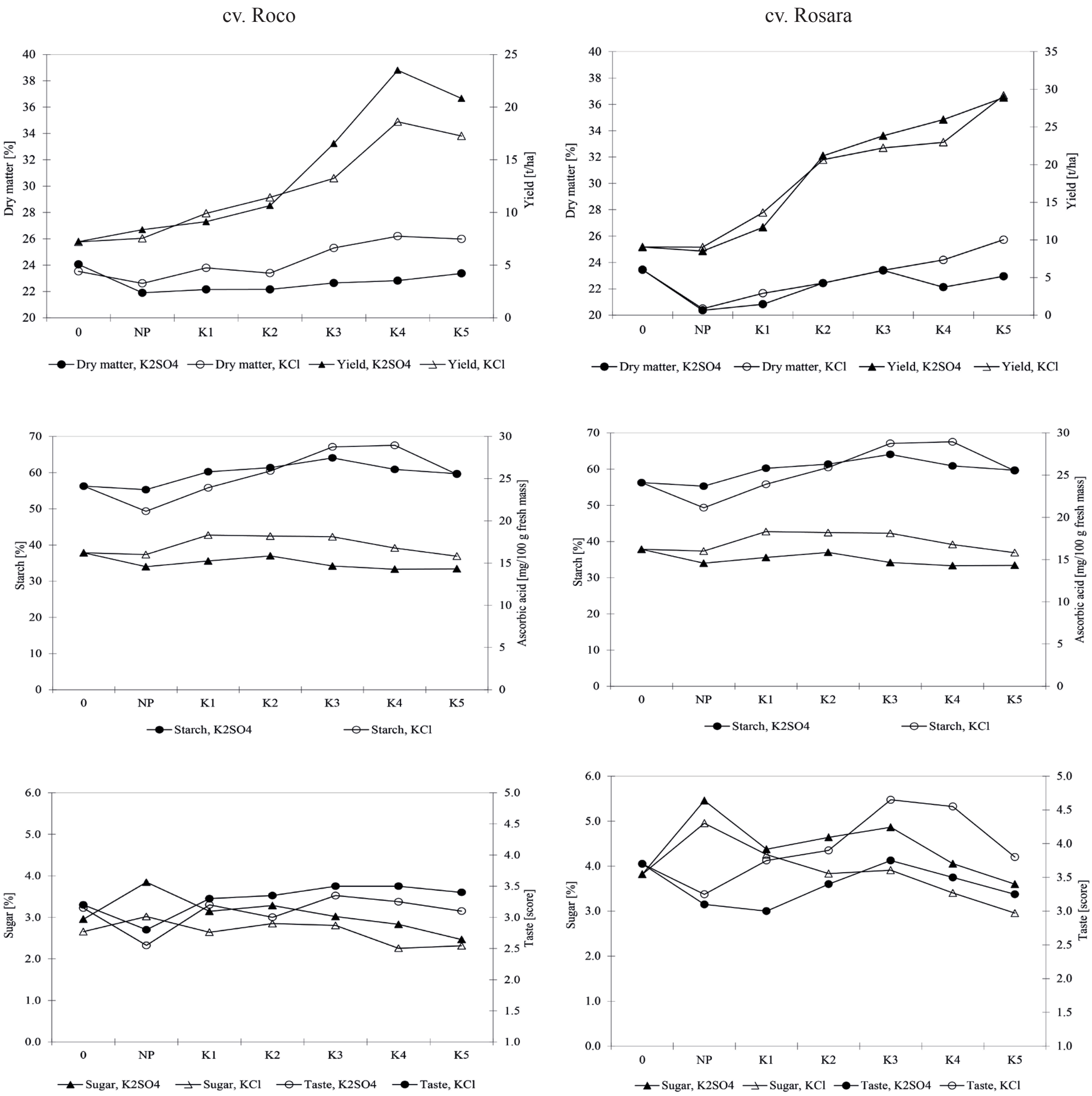

Figure 1. The effect of fertiliser source on tuber yield and quality in the long-term field experiment on Haplic Luvisol in the forest steppe zone of West Siberia (Russia)

Starch content

Starch content of potato tubers, grown in our experiment, averaged 59.7 ± 4.8% over all the variants. Similar to tuber yield and DM, K fertilisation rate was also found to be the major factor in the starch content variance (Table 2). In contrast to tuber yield and DM, however, the interaction between the K fertilisation rate and cultivar had more pronounced effect on starch content, as the studied cultivars had different response patterns to K application rate: Roco tubers had about similar starch content up to K3 rate, followed by a decrease in K4 and K5 (Table 4), while Rosara tubers in all K-fertilised plots increased starch content (Table 5), albeit, similar to Roco tubers, decreasing under K5 rate. Slight decrease in tuber starch content with increase of potassium fertilisation rate was found earlier on loamy podzolic soil in the Smolensk region in Russia (Konova *et al.* 2016); however, on the heavy loamy podzolic soil the effect of increasing K fertilisation rate did not affect tuber starch content (Mikhailova *et al.* 2013).

The chemistry of K fertiliser had no effect on starch content in potato tubers of both cultivars (Table 3); this finding agrees with other findings from experiments with similar fertilisation (Westermann *et al.* 1994; Sharma *et al.* 2011), as well as with organic, biological and combined fertilisation (El-Sayed *et al.* 2015).

Sugar content in tubers

Averaged over all fertilisation variants and cultivars, sugar content in tubers was 3.5±1.0%. The major portion of sugar content variance resulted from potato cultivar properties, while K fertilisation rate explained 20% of the total data variance (Table 2). The chemistry of K fertiliser markedly influenced sugar content in tubers, the latter being lower (albeit not statistically significant in Roco tubers) under potassium sulphate addition (Table 3, Figure 1). Sugar content in both cultivars displayed a tendency to decrease with increasing K application rate (Tables 4, 5), resulting in 30% and 37% decrease in K5 variant for Roco and Rosara, respectively. Thus the rate of sugar belowground translocation to and accumulation in tubers did not seem to match tuber production rate under increased K fertilisation, i.e. at the rate of 150 kg K/ha.

Ascorbic acid (AA) content in tubers

Averaged over all fertilisation variants and cultivars, AA content in tubers was 13.8±2.6 mg/100 g fresh mass, being within the same range (King & Slavin 2013) or at the lower part of the AA content range in potato tubers reported elsewhere (Han *et al.* 2004). Among the studied tuber chemical properties, AA content was the one most influenced by cultivar peculiarities (Table 1), as averaged over all fertiliser variants studied AA content in Roco tubers (11.7±1.1 mg/100 g fresh mass) was lower than in Rosara tubers (16.0±1.6 mg/100 g fresh mass, $P \leq 0.001$). Potassium sulphate, as compared to potassium chloride, was found to increase AA content in tubers of both cultivars (Table 3), the effect being 2 times more pronounced in Rosara tubers (16%). The rate of K fertiliser addition had minor contribution into

T a b l e 2

ANOVA results for tuber yield and quality for Roco and Rosara potato cultivars grown in the forest-steppe zone of West Siberia under different potassium fertilisation rates and forms: factor contribution into the total data variance

Factor	Yield	Content in tubers				Tuber taste
		Dry matter	Starch	Sugar	Ascorbic acid	
Cultivar (n=1)*	**0.18****	**0.08**	0.01	**0.42**	**0.72**	**0.10**
Form of K added (n=1)	**0.01**	**0.17**	0.00	**0.07**	**0.11**	**0.09**
Rate of K added (n=5)	**0.69**	**0.35**	**0.30**	**0.21**	**0.05**	0.16
Cultivar × K form (n=1)	0.00	0.02	0.00	0.00	**0.02**	0.02
Cultivar × K rate (n=5)	**0.07**	0.03	**0.27**	0.02	0.02	0.02
K form × K rate (n=5)	0.02	0.06	0.06	0.00	0.01	0.01
Cultivar × K form × K rate (n=5)	0.00	0.01	0.08	0.01	0.00	0.01
Error (n=24)	0.04	0.28	0.28	0.26	0.06	0.58

*The number of freedom degrees for each factor is given in brackets; **Statistically significant effect ($P \leq 0.05$ level) is highlighted in bold

AA content data variance (Table 2), with some differences between variants displayed only by Roco tubers.

As ascorbic acid is the most abundant antioxidant in potato tubers (Aversano *et al.* 2017), the interplay between AA content and K source and application rate need more detailed studies.

Tuber taste

Tuber taste scores were shown to be affected by potato cultivar and the form of K fertiliser added (Table 2). Tubers grown under K_2SO_4 fertilisation tasted better than the ones grown under KCl fertilisation (Table 3, Figure 1). The rate of K fertilisation did not affect the taste of Roco tubers (Table 4), while Rosara tubers in K3 and K4 variants seemed to improve in taste (Table 5). Interestingly, the taste of tubers grown on the control plot, i.e. without any fertilisation, was quite comparable, and sometimes even better, than the taste of the tubers produced in fertilised plots (Figure 1). As expected, tubers, produced in NP-only plots, i.e. plots with unbalanced fertilisation, tasted worse as compared to tubers grown on other plots, thus underscoring the importance of balanced fertilisation of potatoes, especially grown for personal consumption.

T a b l e 3

Tuber yield and properties of Roco and Rosara potato cultivars grown under different forms of potassium (K) fertilisation in the forest-steppe zone of southern West Siberia (mean ± s.d., n=14)

Tuber properties and yield	Potassium added as			
	KCl		K_2SO_4	
	Roco	Rosara	Roco	Rosara
Tuber yield [kg/m^2]	1.5 ± 0.6[b]*	2.0 ± 0.8[c]	1.3 ± 0.4[a]	2.0 ± 0.7[c]
Dry matter content in tubers [%]	22.5 ± 1.1[ab]	22.0 ± 1.7[ab]	24.6 ± 1.7[c]	23.0 ±1.8[b]
Starch content in tubers [%]	59.6 ± 4.2[a]	60.3 ± 3.2[a]	58.8 ± 5.1[a]	60.0 ± 6.6[a]
Sugar content in tubers [%]	3.1 ± 0.5[a]	4.5 ± 1.0[c]	2.6 ± 0.3[a]	3.9 ± 0.9[b]
Ascorbic acid content in tubers [mg/100 g fresh mass]	11.2 ± 1.0[a]	14.8 ± 0.9[c]	12.1 ± 1.0[b]	17.2 ± 1.2[d]
Tuber taste [score]	3.1 ± 0.9[a]	3.3 ± 0.5[a]	3.3 ± 0.6[a]	4.0 ± 0.6[b]

*Different letters in rows indicate that difference between the numbers they follow is statistically significant at $P \leq 0.05$ level

T a b l e 4

Tuber yield and properties of Roco potato cultivars grown under different potassium (K) fertilisation rates in the forest-steppe zone of southern West Siberia (mean ± s.d., n=4)

Tuber properties and yield	Potassium fertilisation rate						
	Control (no fertilisers)	Control (NP only)	NPK1	NPK2	NPK3	NPK4	NPK5
Tuber yield [kg/m^2]	0.7 ± 0.07[a]*	0.8 ± 0.08[ab]	1.0 ± 0.05[ab]	1.1 ± 0.04[b]	1.5 ± 0.20[c]	2.1 ± 0.5[d]	1.9 ± 0.2[d]
Dry matter content in tubers [%]	23.8 ± 0.6[a]	22.3 ± 1.2[a]	23.0 ± 1.8[a]	22.8 ± 1.0[ab]	24.0 ± 1.6[ab]	24.5 ± 2.5[b]	24.7 ± 1.8[b]
Starch content in tubers [%]	60.4 ± 1.2[a]	59.6 ± 4.3[a]	60.7 ± 1.9[a]	61.2 ± 0.8[a]	62.4 ± 5.9[a]	56.5 ± 3.3[ab]	54.9 ± 6.1[b]
Sugar content in tubers [%]	2.8 ± 0.3[b]	3.4 ± 0.5[b]	2.9 ± 0.3[b]	3.1 ± 0.3[b]	2.9 ± 0.3[ab]	2.5 ± 0.5[a]	2.4 ± 0.1[a]
Ascorbic acid content in tubers [mg/100 g fresh mass]	12.2 ± 1.0[ab]	10.9 ± 0.7[a]	10.8 ± 0.4[a]	12.6 ± 1.2[b]	12.1 ± 1.2[ab]	12.0 ± 1.1[ab]	11.4 ± 1.1[ab]
Tuber taste [score]	3.2 ± 0.6[a]	2.7 ± 1.1[a]	3.3 ± 0.6[a]	3.2 ± 0.6[a]	3.4 ± 0.8[a]	3.4 ± 0.8[a]	3.3 ± 1.0[a]

*Different letters in rows indicate that difference between the numbers they follow is statistically significant at $P \leq 0.05$ level

T a b l e 5

Tuber yield and properties of Rosara potato cultivars grown under different potassium (K) fertilisation rates in the forest-steppe zone of southern West Siberia (mean ± s.d., n=4)

Tuber properties and yield	Potassium fertilisation rate						
	Control (no fertilisers)	Control (NP only)	NPK1	NPK2	NPK3	NPK4	NPK5
Tuber yield [kg/m^2]	0.9 ± 0.2^{a}*	0.9 ± 0.09^{a}	1.3 ± 0.1^{b}	2.1 ± 0.2^{c}	2.3 ± 0.1^{d}	2.4 ± 0.2^{d}	2.9 ± 0.03^{e}
Dry matter content in tubers [%]	23.4 ± 1.4^{b}	20.4 ± 0.9^{a}	21.2 ± 1.1^{a}	22.4 ± 1.2^{ab}	23.4 ± 0.5^{b}	23.2 ± 2.1^{b}	24.3 ± 1.8^{b}
Starch content in tubers [%]	56.3 ± 3.4^{a}	52.3 ± 3.9^{a}	58.0 ± 2.7^{b}	60.9 ± 2.3^{b}	65.6 ±2.7^{c}	64.2 ± 3.9^{c}	59.6 ± 1.1^{b}
Sugar content in tubers [%]	3.8 ± 0.6^{a}	5.2 ± 1.0^{b}	4.3 ± 0.8^{ab}	4.2 ± 1.1^{ab}	4.4 ± 1.2^{ab}	3.7 ± 0.4^{a}	3.3 ± 0.7^{a}
Ascorbic acid content in tubers [mg/100 g fresh mass]	16.2 ± 0.5^{a}	15.3 ± 1.0^{a}	16.8 ± 1.9^{a}	17.0 ± 1.4^{a}	16.4 ± 2.1^{a}	15.5 ± 1.8^{a}	15.1 ± 1.0^{a}
Tuber taste [score]	3.7 ± 0.2^{ab}	3.2 ± 0.2^{a}	3.4 ± 0.6^{a}	3.7 ± 0.4^{ab}	4.2 ± 0.6^{b}	4.0 ± 0.8^{b}	3.5 ± 0.4^{ab}

*Different letters in rows indicate that difference between the numbers they follow is statistically significant at $P \leq 0.05$ level

Potato cultivar performance in respect to tuber quality and sensory properties may vary between years and soils (Neenan *et al.* 1967) due to differences in environmental conditions, such as photosynthetically active radiation, precipitation etc. Only one soil (Luvisol) was used in our experiment; and also we believe our findings can be extended for similar soils in the region, further research is needed on other soil types, such as Chernozems, Cambisols, Podzols etc., widely employed in Siberia for potato production, to enhance taste and dietary benefits of potato tubers for private consumption.

CONCLUSIONS

On the sandy loam soil that has been for several decades in agricultural use and hence depleted of major plant available nutrients potato yield did not respond to solely nitrogen and phosphorus fertilisation, being limited by potassium availability. Potassium fertilisation increased tuber yield significantly, and the effect was cultivar-dependent. More productive potato cultivar was found to be much more responsive to potassium application rate, while not being sensitive to potassium fertiliser chemistry, i.e. potassium chloride versus potassium sulphate.

Thus in agricultural ecosystems with long-term history of cropping, fertilisation schemes should be tailored for specific purposes of potato production. Such tailoring requires better insight into cultivar biochemical and physiological machinery involved in mediating the effects of potassium application on tuber production and dietary quality.

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