AGROECOLOGICAL EFFICIENCY OF SITE-SPECIFIC FERTILISER APPLICATION IN THE NORTH-WEST OF THE RUSSIAN FEDERATION

Nadezhda Tcyganova[1], Aleksei Ivanov[2]
[1]Saint-Petersburg State Agrarian University, Russian Federation
[2]Agrophysical Research Institute, Russian Federation
nats-2012y@yandex.ru, ivanovai2009@yandex.ru

ABSTRACT

The high spatial soil variability is the natural feature of soil covering in the North-West region of the Russian Federation. This heterogeneity requires site-specific management at the field scale. The main objective of the presented research is to examine the effectiveness of site-specific fertiliser application by reference of specific features of the agro micro-landscape conditions. The field site is a 22-ha field located in Leningrad region. The soil was typical and gleyic sod-podzolic. The most important characteristic for the present research is the high spatial variability of soil properties. The introduced crop rotation was: potato – spring barley – perennial grasses of the first and second harvest year – winter wheat. Research factors were (1) control (no fertilisation); CvF - conventional fertiliser application: mineral fertilisers added annually according to conventional agriculture practice; SsF I - mineral fertilisers added annually according to soil properties; SsF II - in 2008 only potassium fertilisers were applied site-specifically to reduce spatial variability of potassium content. During the following years, the after-effect was observed and mineral fertilisers were applied uniformly; SsF III – mineral fertilisers added annually according to yield map data; (2) agro micro-landscapes (accumulative-eluvial, accumulative, eluvial and transite-accumulative). The average data of the five-year investigation show that the highest productivity without fertilisation was gained in the accumulative agro micro-landscape, and the lowest – in the eluvial agro micro-landscape. The highest yield of all investigated crops was harvested when potassium fertilisers had been applied site-specifically. In other cases, the yields were almost equal in conventional and site-specific fertilisation.

Keywords: spatial variability, yield, conventional fertilisation, site-specific fertilisation.

1. INTRODUCTION

One of the main factors for obtaining high crop yields is a rational fertiliser application. The significant achievements in IT-technologies at the turn of Millennium have made it possible not only to collect and process non-generalized status information about variability of soil and crop conditions but to use it for site-specific crop management (Lechner & Baumann, 2000). Precision farming technologies have adopted sequentially, with each providing a degree of marginal benefit to the farmer (Khanna 2001; Roberts et al., 2004). Soil properties differ greatly in their small-scale distribution. The high spatial soil variability is the natural feature of soil covering in the North-West region of the Russian Federation. This heterogeneity requires site-specific management at the field scale to avoid wasting resources, environmental pollution and decreasing soil fertility. For example, uniform nitrogen fertilisation within fields contributes to the global input of reactive nitrogen to terrestrial ecosystems, drainage water and the atmosphere (Galloway et al., 2003; Liu et al., 2010; Fowler et al., 2013). This research was done by Saint-Petersburg State Agrarian University in close cooperation with Agrophysical Research Institute. The main objective of the presented research is to examine the effectiveness of site-specific fertiliser application by reference of specific features of the agro micro-landscape conditions.

2. METHODOLOGY

Experimental part of the study was performed in field trials of Menkovskaya Research Station of Agrophysical Research Institute in 2008 – 2013. The introduced crop rotation was: potato (2008) – spring barley undersown with perennial grasses (2009) – perennial grasses of the first harvest year (a mixture of timothy with meadow fescue) (2010) – perennial grasses of the second harvest year (a mixture of timothy with meadow fescue) (2011) – winter wheat (2012). Crop varieties registered in the Russian Federation were investigated: potato Nevsky, spring barley Suzdalets, timothy Leningradskaya 204, meadow fescue Suydinskaya, winter wheat Inna. The field site is a 22-ha field located in Leningrad region, Gatchina district. The soil was typical and gleyic sod-podzolic developed on red moraine sandy loam (according to the USSR soil classification).

Soil agrochemical characteristics were as follows: pH_{KC1} (potentiometrically on 1 M KCl suspension) – 5.50, hydrolytic acidity (by Kappen method modified by CINAO) – 2.99 mg-eq. per 100 g of soil, total exchangeable basis (by Kappen method) – 15.50 mg-eq. per 100 g of soil, organic matter content (oxidizing the soil with potassium dichromate ($K_2Cr_2O_7$)) – 4.36%, the content of plant available phosphorus and potassium (by Kirsanov method modified by CINAO) – 434 and 197 mg kg-1 of soil, respectively.

The research factors were: factor A – agro micro-landscapes and factor B - fertilisation. To investigate the influence of agro micro-landscapes the key-site method was used. There were 4 key sites: accumulative-eluvial, accumulative, eluvial and transite-accumulative. The following fertiliser applications were used: C – control treatment: without fertilisers; CvF – conventional fertiliser application: mineral fertilisers added annually according to conventional agriculture practice; SsF I – the first site-specific fertiliser application: mineral fertilisers added annually according to soil properties; SsF II – the second site-specific fertiliser application: in 2008 only potassium fertilisers were applied site-specifically to reduce spatial variability of potassium content. During the following years, the after-effect was observed and mineral fertilisers were applied uniformly; SsF III – the third site-specific fertiliser application: mineral fertilisers added annually according to yield map data. Experimental data evaluation was done using two-factor analysis of variance by least significant difference (LSD_{05}).

Information about the weather was obtained from the Menkovskaya Research Station. Almost all vegetation periods had a higher temperature regime as compared to the long-term average. In the vegetation periods of 2008 – 2012 the precipitation was 1.6 – 2.6 times as high as the long-term average. In the vegetation periods of 2008 – 2012, excessive moisture was observed, and the hydrothermal coefficient (HTC) was 2.0 – 3.5.

The soil preparation was conventional for crops in the North-West region of the Russian Federation. All crops were harvested at the time of plant maturity and evaluated for yield. Registration plot area was 6000 sq. m; the experiment was carried out in fourfold replication. The yield of barley, perennial grasses and winter wheat was recalculated in t ha-1 at standard moisture and 100% purity. The yield of potato was recalculated in t ha-1 at natural moisture and 100% purity.

3. RESULTS

The most important characteristic for the present research is the high spatial variability of soil properties. Soil data were analyzed statistically for descriptive statistics such as mean, maximum, minimum and coefficient of variation (CV). The parameters based on descriptive statistics can be seen from table 1. It shows that the spatial variation of organic matter and plant available potassium is the largest and the coefficient of variation is 26 and 25%, respectively. The spatial variability of plant available phosphorus and exchange soil acidity is less and the coefficient of variation is 18 and 6%, respectively.

Table 1. The statistics value of soil parameters

Item	Minimum	Maximum	Mean	CV, %
Organic matter	1.70	7.54	4.36	26
pHKCl	4.30	6.90	5.50	6
Plant available phosphorus (P_2O_5), mg kg^{-1}	232	580	434	18
Plant available potassium (K_2O), mg kg^{-1}	76	360	197	25
Hydrolytic acidity, mg-eq. per 100 g of soil	2.99	0.84	4.82	23
Total exchangeable basis, mg-eq. per 100 g of soil	15.5	6.0	26.4	25

The factual fertiliser rates applied according to the scheme and the average annual productivity of crop rotation are presented in Table 2. The results presented in Table 2 show that all average data of the five-year investigation show that the highest productivity without fertilisation was gained in the accumulative-eluvial agro micro-landscape, and the lowest – in the eluvial agro micro-landscape. The highest yield of all investigated crops was harvested when potassium fertilisers had been applied site-specifically (SsF II). In other cases, the yields were almost equal in conventional and site-specific fertilisation.

Table 2. Average annual productivity of crop rotation depending on fertilisation and agro micro-landscape conditions

Agro micro-landscape Factor A	Fertilisation Factor B	Average annual fertiliser rates	Main product yield, t of grain units ha^{-1}	Yield increase	
				$t\ ha^{-1}$	%
Accumulative-eluvial	C	0	2.03	-	-
	CvF	$N_{94}P_{45}K_{63}$	3.77	1.74	85
	SsF I	$N_{107}K_{55}$	4.22	2.19	107
	SsF II	$N_{94}P_{45}K_{88}$	4.34	2.31	113
	SsF III	$N_{108}P_{53}K_{123}$	4.12	2.09	102
Accumulative	C	0	1.82	-	-
	CvF	$N_{94}P_{45}K_{63}$	4.11	2.29	127
	SsF I	$N_{98}K_{59}$	4.20	2.38	133
	SsF II	$N_{94}P_{45}K_{63}$	4.54	2.72	150
	SsF III	$N_{89}P_{44}K_{59}$	4.31	2.49	138
Eluvial	C	0	1.61	-	-
	CvF	$N_{94}P_{45}K_{63}$	3.66	2.05	127
	SsF I	$N_{104}K_{52}$	4.04	2.43	150
	SsF II	$N_{94}P_{45}K_{63}$	3.96	2.35	146
	SsF III	$N_{96}P_{45}K_{60}$	3.86	2.25	140
Transite-accumulative	C	0	1.95	-	-
	CvF	$N_{94}P_{45}K_{63}$	3.95	2.00	102
	SsF I	$N_{91}K_{51}$	4.01	2.06	106
	SsF II	$N_{94}P_{45}K_{93}$	4.41	2.46	126
	SsF III	$N_{96}P_{45}K_{67}$	4.07	2.12	108
LSD_{05} A				0.35	
LSD_{05} B				0.31	
LSD_{05} AB				*ns	

4. Discussion

According to the experimental results, the lowest potato tuber yields were harvested in accumulative and eluvial agro micro-landscapes. These yields fluctuated from 9.01 t ha^{-1} to 10.40 t ha^{-1}. Potato tuber yields with site-specific fertilisation according to soil properties were almost equal to conventional treatment. The highest potato tuber yield was achieved under site-specific potassium fertilisation. Potato tuber yield in the last mentioned treatment was 8 – 22% higher compared to conventional treatment.

Unfertilised barley produced significantly higher yields in the accumulative agro micro-landscape compared to other ones. The significant difference between conventional and site-specific fertilisation was only in accumulative-eluvial agro micro-landscape. The yield increase fluctuated from 0.57 t ha^{-1} to 1.17 t ha^{-1}.

In 2010 the highest perennial grasses hay yield without fertilisation were harvested in accumulative and accumulative-eluvial agro micro-landscapes because of their better nutrient and water status. The significant yield gain was harvested when mineral fertilisers had been applied according to the soil properties under the conditions of eluvial agro micro-landscape. In accumulative-eluvial agro micro-landscape fertilisation according to potassium content was effective as well.

The perennial grasses hay yields in 2011 were less than in 2010. It was because of gradual soil compaction till steady-state density. The yield gain was the lowest in eluvial agro micro-landscape. It is probably related to the large nitrogen leaching losses because of excessive precipitation.

According to the experimental results from 2012, the lowest winter wheat grain yield was obtained without fertilisers. In the current research conventional nitrogen fertiliser was significantly ($p < 0.05$) increasing winter wheat grain yield. All fertiliser applications used have a significant effect on winter wheat grain yield increase if compared to control. In the treatments with site-specific fertilisation winter wheat produced 0.40 – 1.31 t ha^{-1} higher yields in comparison with conventional fertilisation almost independently of agro micro-landscape conditions. Winter wheat produced significant yield gain with the above mentioned treatments except the transite-accumulative agro micro-landscape.

5. Conclusions

All the investigated factors (agro micro-landscapes and fertilisers) influenced the crop yields. Conventional fertilisation has significant impact on the crop productivity. In a gleyic sod-podzolic soil, crop fertilisation at a N94P45K63 fertiliser rate resulted in a yield increase by 85 – 127%. Site-specific fertilisation according to soil properties increases the crop productivity. The highest yield increase (113 – 150%) was achieved in the treatment site-specifically fertilised by potassium in 2008. Compared to conventional fertilisation, the yield under SsF II was 8 – 15% higher. The main advantage of site-specific fertiliser application is not only to increase the yield but to reduce the spatial variability of soil properties. According to our research, the coefficient of variation of plant available potassium was reduced from 25 to 9%. The agro micro-landscape conditions influence significantly on crop yields and crop rotation productivity. The rates of fertilisers should be change according to the micro-landscape conditions.

References

Bechar, A. and Vigneault, C. (2016) 'Agricultural robots for field operations: Concepts and components', Biosystems Engineering, 149, pp. 94–111. doi: 10.1016/j.biosystemseng.2016.06.014

Fowler, D., Coyle, M., Skiba, U., Sutton, M. A., Cape, J. N., Reis, S., et al. (2013) 'The global nitrogen cycle in the twenty-first century', Philosophical Transactions of the Royal Society B: Biological Science, 368(20130164), pp. 1–13

Galloway, J. N., Aber, J. D., Erisman, J. W., Seitzinger, S. P., Howarth, R. W., Cowling, E. B., et al. (2003) 'The nitrogen cascade', BioScience, 53(4), pp. 341–356

Khanna, M. (2001) 'Sequential adoption of site-specific technologies and its implication for nitrogen productivity: A double selectivity model', American Journal of Agricultural Economics, 83, pp/ 35 – 51

Lechner, W. and Baumann, S. (2000) 'Global navigation satellite systems', Computers and Electronics in Agriculture, 25, pp. 67 – 85

Liu, J., You, L., Amini, M., Obersteiner, M., Herrero, M., Zehnder, A. J. B., et al. (2010) 'A high-resolution assessment on global nitrogen flows in cropland', Proceedings of the National Academy of Science of United States of America, 107(17), pp. 8035–8040

Roberts, R.K., English, D.C., Larson, J.A., Cochran, R.L., Goodman, W.R., Larkin, S.L., et al. (2004) 'Adoption of site-specific information and variable-rate technologies in cotton precision farming', Journal of Agricultural and Applied Economics, 30, pp. 143 – 158