Spatial Variability of Soil Fertility Parameters and Efficiency of Variable Rate Fertilizer Application in the Trans-Volga Samara Region

By A. Tsirulev

Precision agriculture approaches were compared to routine current management for conducting soil fertility assessment in a recent study. Measurement of soil spatial variability in precision agriculture was accomplished using GPS equipment with precise fixing of soil sampling points, automatic soil sampler, and special software to map various soil fertility parameters, including soil nutrient content. Both spring wheat yield and net profit were highest with variable rate fertilizer application in the on-farm research experiment.

In this region of Russia, routine soil sampling for agrochemical analysis is done manually and, most importantly, without precise reference of sampling points to a map. Thus, during the next soil sampling it is not possible to claim with confidence that soil samples are taken from the same place. Such an approach makes it difficult to characterize the status and dynamics of soil fertility changes in the field that are needed for fine tuning of fertilizer application rates. This negatively affects both the economics of agricultural production and the environment (Yakushev, 2002).

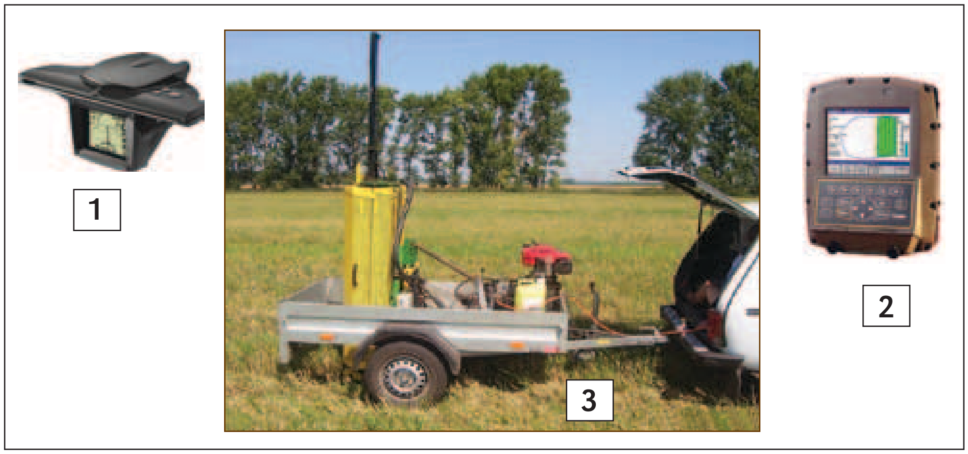

Figure 1. Automatic soil sampling equipment: 1 – GPS navigation system; 2 – field computer; 3 – soil sampler.

The Ministry of Agriculture and Food of Samara Oblast initiated and supported a special research project to test a new method of discrete soil sampling for soil fertility survey using GIS and GPS navigation systems. The research work was conducted on fields of the agricultural enterprise Samara-Solana in Stavropol District of Samara Oblast. Common chernozem is a predominant soil type of the area. The variability of four soil fertility factors, including organic matter (humus) content, available P and K... extraction with 1% $(NH_4)_2CO_3$... and soil pH, was measured in 2007 in 10 fields totalling 776 ha.

Soil sampling was done by an automatic mobile complex that included a navigation system with built-in high-precision GPS receiver, field computer with special software, and automatic soil sampler **(Figure 1)**. Fields were divided into basic soil sampling areas of 4 ha (200 m x 200 m) and the automatic soil sampler, moving diagonally, took 10 soil samples (0 to 30 cm depth) from each basic area. These 10 soil samples were mixed and one soil sample was prepared for the basic area and then used in soil fertility tests (with the traditional approach, one mixed soil sample is taken from the area of 25 to 40 ha). As a result, selected fields, depending on field acreage, were characterized by 10 to 30 soil samples (number of observations).

Table 1 shows results of soil fertility analysis of the agricultural enterprise's fields, including mean, confidence interval, coefficient of variation, and number of samples used in the analysis. According to these data, available P and K content in the soil were found to be the most variable parameters. The coefficients of variation for available P ranged from 16% to 51% and for available K, from 18% to 37%. Soil humus content had medium variability (7 to 15%), and the lowest variability was revealed for soil pH (2 to 5%). Thus, this study indicated considerable variability in soil fertility characteristics of chernozemic soil, particularly for available P and K, even on leveled fields of this advanced agricultural enterprise. Variable rate fertilizer application, hence, should be considered as an important method for making soil fertility distribution more uniform. According to recent estimates, variable rate fertilizer application in current economic conditions in Russia may be reasonable if spatial variability in the content of soil nutrients is about 20% or more (Afanasyev, 2010).

Using GIS software, soil fertility properties from the basic areas were interpolated to the whole field, to reveal the spatial heterogeneity of soil nutrients and create spatial distribution maps showing zones with the same level of nutrient content **(Figure 2)**. In this study, final maps indicate 20 zones (the number of zones is adjusted) over the field for each soil parameter. Such a detailed mapping of soil nutrient content is required for calculating fertilizer application rates for soil management zones with different fertility status. Calculation of fertilizer rate based on expected crop yield is done using software with a built-in equation editor, taking into consideration soil nutrient content of basic areas. Fertilizer variable rate application maps were developed for each basic area over the field, but soil management zones have a square form sized

Abbreviations and notes: GPS = global positioning system; GIS = geographic information system; N = nitrogen; P = phosphorus; K = potassium; RUB = Russian Rubles (approx. 30.6 RUB/USD).

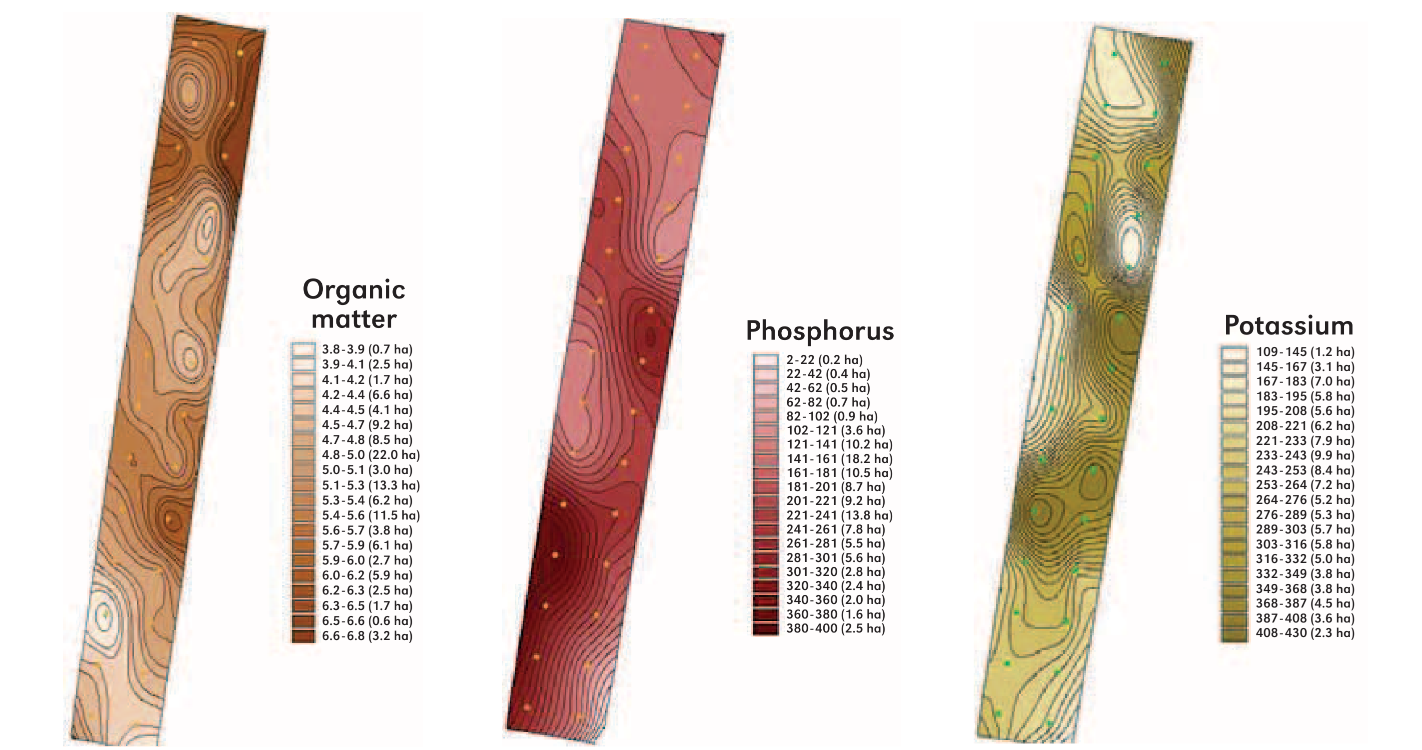

Figure 2. Distribution of organic matter and available P and K (as P_2O_5 and K_2O, respectively) at experimental field number 3 (20 zones) of the agricultural enterprise in Stavropol District, Samara Oblast.

Table 1. Soil fertility analysis of agricultural enterprise's fields in Stavropol District of Samara Oblast, including mean, confidence interval, coefficient of variation, and number of samples used in the analysis (Tsirulev et al., 2008).

	Field number									
Soil fertility parameters	1	2	3	4	5	6	7	8	9	10
Organic Matter[1], %	4.63	4.78	5.32	5.05	5.06	5.27	4.73	4.62	4.44	4.33
	4.43-4.83	4.36-5.20	4.68-5.96	4.81-5.29	4.54-5.58	4.89-5.65	4.47-4.99	4.45-4.79	4.12-4.76	4.12-4.54
	8.8	8.9	15.1	6.9	12.3	7.7	9.5	7.0	10.6	7.2
Available P (as P_2O_5), ppm	168	153	188	174	190	225	281	226	154	116
High = 46 to 60 ppm	144-192	73-232	140-237	156-191	165-214	157-293	248-313	202-250	123-185	84-148
	27.0	51.4	32.9	15.9	16.1	31.7	20.5	18.5	30.3	42.5
Available K (as K_2O), ppm	228	215	268	286	288	331	363	261	210	237
High = 401 to 600 ppm	185-270	177-254	199-337	220-352	203-374	215-447	300-426	220-303	176-242	184-290
	35.2	17.8	32.8	35.7	36.4	36.9	31.1	27.3	24.5	34.8
pH (H_2O)	6.73	6.97	6.61	6.13	6.19	6.76	6.56	6.75	7.02	7.03
	6.59-6.87	6.78-7.16	6.46-6.76	6.01-6.25	5.95-6.43	6.54-6.98	6.41-6.71	6.63-6.87	6.90-7.14	6.91-7.15
	4.02	2.54	3.00	3.19	5.12	3.64	3.95	2.97	2.34	2.51
n	30	10	15	21	14	11	27	25	20	21

[1] Upper row – mean; middle row – minimum-maximum values (confidence interval); bottom row – coefficient of variation, %.

according to the coverage of a variable rate fertilizer spreader (polygons converted to blocks).

A short-term, on-farm research experiment was conducted in the same agricultural enterprise to investigate the benefits of variable rate fertilizer application to spring wheat based on measurement of spatial variability in available P and K content in the soil (Tsirulev, 2008). The experiment consisted of five treatments: 1) extensive crop management approach without fertilizer use (control), 2) ordinary technology (average fertilizer practice, without soil testing), 3) ordinary technology with GPS navigation (to monitor and control agricultural machinery operations in the field), 4) intensive technology (fertilizer rates calculated using the balance method based on expected wheat yield and the average available P and K content in the soil measured with the traditional soil sampling procedure), 5) intensive technology with GPS navigation and variable rate fertilizer application.

The lowest grain yield of spring wheat was obtained from the control treatment with extensive crop management technology and zero fertilizer use – 1.35 t/ha **(Figure 3)**. Other treatments gave yield increases of 0.42 to 0.70 t/ha above the control. The use of GPS navigation and variable rate fertilizer

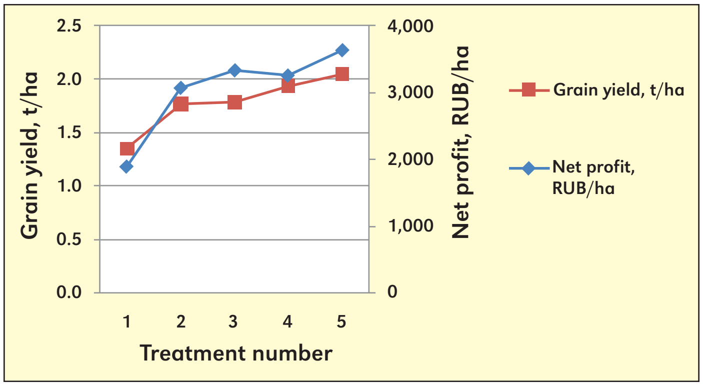

Figure 3. Grain yield of spring wheat and net profit as affected by crop management technology in on-farm research experiment conducted in 2007 at the agricultural enterprise's field in Stavropol District, Samara Oblast (Tsirulev, 2008). Treatments:

1 – Extensive technology without fertilizer use (control)
2 – Ordinary technology (average fertilizer practice)
3 – Ordinary technology with GPS navigation
4 – Intensive technology (fertilizer rates calculated using the balance method)
5 – Intensive technology with GPS navigation and variable rate fertilizer application

application in the 5th treatment were the most efficient in increasing grain yield of spring wheat (to 2.05 t/ha) compared to other technologies studied in the experiment. The benefit of crop management under precision agriculture technologies was uniform (without gaps and overlaps) application of mineral fertilizers and plant protection inputs on the experimental field. At the same time, areas with lodging of spring wheat were observed in plots receiving the treatment with intensive crop management technology, but without GPS navigation. This was because of overlap in applying broadcast N fertilizer **(Figure 4)**.

Net profit was highest for the 5th treatment (3,638 RUB/ha) where precision agriculture approaches were used, and exceeded by 11% the net profit for the 4th treatment (3,264 RUB/ha) when fertilizer rates were calculated using the balance method based on the average available P and K content in the soil **(Figure 3)**. The measurement of spatial variability in available P and K indicated areas with high or very high levels for both nutrients, which for the 5th treatment did not require P and K fertilizer application according to the standard soil fertility classes. Thus, fertilizer expenses decreased by 9%

Figure 4. Lodging of spring wheat in treatment No. 4 under intensive technology without GPS navigation. Overlap in applying broadcast N fertilizer resulted in lodging.

(from 1,552 to 1,411 RUB/ha) compared to the 4th treatment where fertilizer rates were calculated by the balance method based on the analysis of a mixed soil sample from a large area.

It may be concluded, therefore, that measurement of the spatial heterogeneity of soil fertility factors enabled more precise agrochemical analysis of arable fields compared to the routine approach widely used in soil fertility surveys. Variable rate fertilizer application, moreover, considerably increased the efficiency of mineral fertilizer use. It is important to note that the application of fertilizers at average rates based on the traditional soil sampling method may result in both under- and over-fertilization on some parts of the field. The latter factor may have a negative impact on the environment. BC

Dr. Tsirulev is Director, Foundation for Agricultural Education, located in Ust-Kinelski, Samara Oblast; e-mail: fso-kinel@rambler.ru. *The author acknowledges help from Dr. V. Nosov, Director, IPNI Southern and Eastern Russia Region, with preparing this article.*

References

Yakushev, V.P. 2002. Petersburg Nuclear Physics Institute, St. Petersburg. 458 p. (In Russian).

Afanasyev, R.A. 2010. Problems of Agrochemistry and Ecology. 1: 38-44. (In Russian).

Tsirulev, A.P., A.S. Borovkova, and A.P. Golovochenko. 2008. Proc. Samara State Agri. Academy. 4: 62-65. (In Russian).

Tsirulev, A.P. 2008. The experience of effective use of resource conservation agrotechnologies in the forest-steppe Trans-Volga region. Paper presented at the 10th Anniversary Russian Agricultural Exhibition Gold Autumn 2008, Moscow, Russia, 13 October, 2008. (In Russian).

IPNI Introduces "Nutrient Source Specifics" Series

IPNI has introduced a new series of one-page, condensed fact sheets highlighting common fertilizers and nutrient sources in modern agriculture. The series is called "Nutrient Source Specifics".

"These topics offer brief information about the production, agricultural use, management practices, and chemical properties of common fertilizer materials," said IPNI President Dr. Terry L. Roberts. "One of our thematic work groups saw the need for this kind of information and we believe the series format will be useful in providing a quick reference library as we add to it. However, we also encourage individuals to consult with local experts regarding specific nutrient use."

One of the goals of IPNI is to provide science-based plant nutrient and fertilizer information to a wide range of audiences.

Nutrient Source SPECIFICS

Written by IPNI scientific staff, Nutrient Source Specifics topics are primarily for educational use by a non-technical audience. The list of topics currently consists of: 1) urea; 2) polyphosphate; 3) potassium chloride; 4) compound fertilizer; 5) potassium sulfate; 6) potassium magnesium sulfate: langbeinite; 7) urea-ammonium nitrate; 8) thio sulfate; 9) monoammonium phosphate (MAP); and 10) ammonia.

The series will be available as individual PDF files at the IPNI website: >www.ipni.net/specifics<.