PRINCIPLES OF PRECISION AGRICULTURE IN ON-FARM SPRING WHEAT FERTILIZATION EXPERIMENT

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Abstract. Precision farming is an innovative conception of agricultural production. European farmers apply the principles of precision agriculture (PA) fragmentary; therefore, we need complex investigations of technological processes in conditions of PA. In 2013-2014, the demonstrational on-farm field experiment was carried out at Alfredas Bardauskas agricultural farm, Raseiniai reg., Lithuania. The aim of the experiment was to evaluate the impact of PA technological processes on soil fertility, distribution of nutrients, weed stand density, productivity and quality of spring wheat crop. Two different agricultural systems were investigated – conventional (CA) and precision (PA). In CA, mineral fertilizers were freely distributed before sowing. In PA, fertilization rate was chosen according to the measurements of soil electrical conductivity with a mobile machine "Veris 3150 MSP" and crop stand optical properties with "OptRx" sensors. In PA conditions, spring wheat plants were well distributed and effectively competed with weeds. In PA, the quantity of P_2O_5 in the soil varied from 108 to 212 mg·kg^{-1}, K_2O – from 97 to 143 mg·kg^{-1}, pH – from 6.5 to 7.4. At the beginning of the experiment, in CA conditions, the yield of grain, quantity of protein and gluten was by 3.9, 2.8 and 3.8 % higher than in PA. The differences of spring wheat productivity and quality mainly depended on higher proportion of available nutrients in CA soils.

Keywords: fertility mapping, precision agriculture, spring wheat, yield and quality.

Introduction

Precision agriculture (PA) (in English "precision farming", "site-specific farming", "farm by the foot", "spatially variable crop production", "grid farming"), (in German "teilflächenspezifische bewirtschaftung", "teilflächenbewirtschaftung", "kleinräumige bestandsführung", "lokales Ressourcenmanagement") is an innovative conception of agricultural production based on information technologies in crop production. PA contains different types of new technologies, such as Global Positioning System (GPS), technologies of sensors, geo-information systems.

Success in PA is closely related to the questions how well it can be applied to assess, manage, and evaluate the space-time continuum in crop production [1]. The variability of PA results depends on the field topography, crop yield, soil properties and nutrients, crop nutrients, crop canopy volume, density and biomass, water content and availability, rainfall distribution, spread of pests (disease, weeds and insects), tillage practice, crop rotation and other factors [2-7]. Soil parameters with low variance (pH, quantity of P or K) might be more easily managed than those with large variance (infestation of insects) [1]. Impact of agricultural factors may be evaluated using plenty of sensor types and instruments such as field-based electronic sensors, spectroradiometers, machine vision, airborne multispectral and hyper spectral remote sensing, satellite imagery, thermal imaging and others. Sensing techniques for crop biomass, weed, soil properties and nutrients testing are most useful and can provide the data required for site specific management [6]. The electrical and electromagnetic on-the-go soil sensors have been mainly used in PA. Such sensors often perform electrical conductivity measurements. This information should not be used directly because the results depend on the soil texture, organic matter, salinity, moisture content. However, electrical and electromagnetic sensors give valuable information about soil differences and present a chance to divide the field into smaller and relatively homogeneous areas [8]. Wavelengths of electromagnetic radiation initially focused on a few key visible or near infrared bands. In our days, electromagnetic wavelengths are in use range from the ultraviolet to microwave spectrums. Advanced applications are light detection and ranging (LiDAR), fluorescence spectroscopy, and thermal spectroscopy, more traditional - visible and near infrared portions of the spectrum [9].

May PA be profitable? Joshinke et al. [10] summarized that PA tools had the potential to save money for farmers by increasing efficiencies in broad acre cropping systems. Batte and Arnholt [11] collected information about the future of PA technologies. They concluded that all of the involved USA growers were optimistic about the future of PA. Godwin et al. [12; 13] found that a farm with

250 ha of cereals, where 20-30 % of the area could respond positively to spatially variable nitrogen, would need to achieve a yield increase from 0.25 to 1.1 t·ha^{-1}.

The aims of this paper are to: (1) evaluate soil electrical conductivity and chemical properties, (2) create field fertilization maps, and (3) find differences between conventionally and in precision way cultivated spring wheat crops.

Materials and methods

In 2013-2014, the demonstrational on-farm field experiment was carried out at Alfredas Bardauskas agricultural farm, Raseiniai reg., Lithuania. The experimental soil was light loam. In the area of 10 ha, spring wheat was cultivated in conditions of conventional (CA) and precision agriculture (PA). In CA, the field was fertilized in a scattered manner according to the nutrients need of one ton of grains ($N_{22}P_{10}K_{20}$). In PA, the fertilization rate was about $N_{120}P_{55}K_{110}$. In the on-farm experiment, agro-technical operations were similar in both systems (Table 1). The farmer grew early spring wheat variety “Taifun”. Average height of a plant is 78 cm. Plants of this variety are stable for lodge, and have good processing quality of grain. Spring wheat was sowed on the 20th of April. Sowing rate was 220 kg·ha^{-1}. Distance between rows – 16.8 cm, sowing depth – 4-5 cm. We used conventional chemical pest control system.

Table 1

Agro-technical operations and equipment

Operation	Equipment	
	Tractor	Machine
Mouldboard ploughing	John Deere 8330	Kuhn Challenger 8NSH
Pre-sowing tillage	John Deere 8330	Vaderstad NZ Aggressive 900
Measurements of electrical conductivity	John Deere 6530	Veris 3150 MSP
Fertilization	John Deere 6530	Amazone ZA-M 1500 profiS
Measurements of crop optical properties	John Deere 6530	Amazone ZA-M 1500 profiS with sensor OptRx
Sowing	John Deere 7530	John Deere 750 A, working width 6 m
Spraying	John Deere 6530	John Deere 732, working width 24 m
Harvest	-	Claas Lexion 560

In the on-farm experiment, the crop stand density was evaluated twice – at the beginning and at the end of vegetation. The data of the second evaluation are presented. Stand density was performed in the longitudinal metre of row in no less than 5 spots of each replication (four) of systems. The data were recalculated into m^2. The biometric parameters of crop were established in the crop ear stage. We took 10 plants for test from each experimental plot.

Soil agrochemical properties were established according to the chemical methods of evaluation. Samples were taken with agro-chemical auger in 10-15 spots per plot. Analyses were performed in 4 replications. Soil electric conductivity was tested with a mobile machine “Veris 3150 MSP“ (Fig. 1). The machine is able to test the soil electrical conductivity in 0-30 and 0-90 cm depths and has GPS system. Mapping of electrical conductivity was performed with the computer program “SMS Advanced“ (USA, AgLeader Ltd.).

We used OptRx sensors for evaluation of the crop optical properties (Fig. 2). OptRx sensors measure reflected irradiation in infrared and red diapasons of spectrum.

The parameters of spring wheat yield were evaluated through cutting of 30 productive stems from each experimental plot. We evaluated the average length of an ear, number of grains in an ear, mass of grains in one ear, mass of 1000 grains, yield of grains. Moisture of grains was established by drying and weighting methods, quantity of wet gluten – with apparatus “Glutomatic” (standard LST 1522:2004), sedimentation index – according to standard ISO 5529:2007, quantity of proteins – by the Kjeldal method.

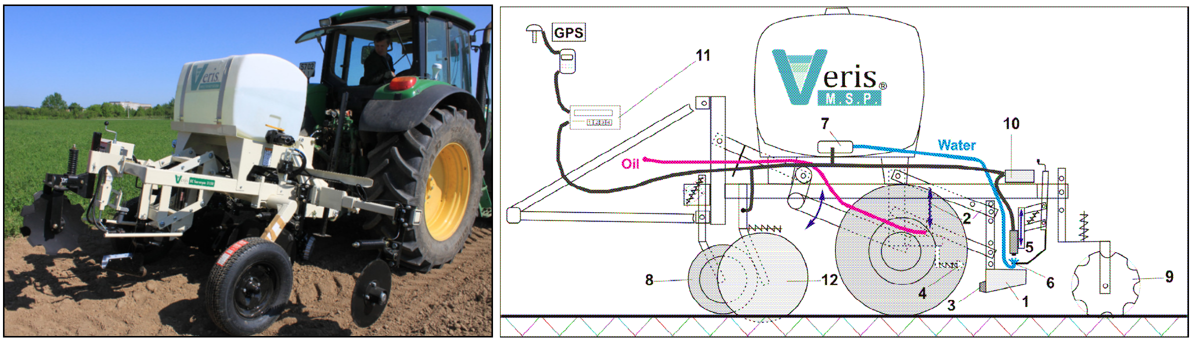

Fig. 1. **Veris MSP machine with Soil pH Manager system:** 1 – scoop; 2 – mechanism of scoop lifting; 3 – adapter; 4 – hog; 5 – pH sensors; 6 – water supply with nozzles; 7 – water tank; 8 – plant residues removal; 9 – furrow filling hoes; 10 – controller; 11 – data recorder; 12 – sensor of soil electrical conductivity

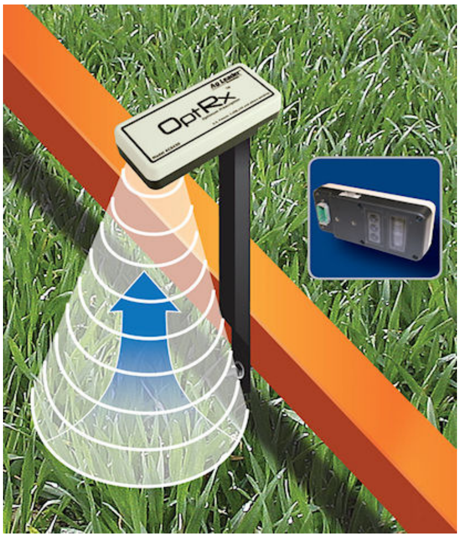

Fig. 2. **Sensor of crop optical analysis OptRx (Ag Leader® Technology, USA)**

Results and discussion

According to the tests of apparatus "Veris" and agrochemical analyses of the soil, in PA field distribution of viable P (P_2O_5) was uneven. The quantity of P varied from 107 to 212 mg·kg^{-1} (Fig. 3, a). An average quantity of P in PA field was 142.4 mg·kg^{-1}, whereas in CA – 151 mg·kg^{-1} or 6 % higher. In PA field, differences in P distribution were even by the first fertilizing with simple superphosphate.

Proportion of viable potassium (K_2O) in PA field was distributed more even than viable P, however, its quantity varied from 97 to 143 mg·kg^{-1} (Fig. 3, b). On the average, the amount of K in PA field was 123.1 mg·kg^{-1} and in CA – 160 mg·kg^{-1} or about 30 % higher.

In PA field, we established little variation of soil pH – from 6.5 to 7.4 (Fig. 3, c). In CA field, mean soil pH was 6.1.

The test of soil electrical conductivity showed that the dominant soil was sandy loam (Fig. 3, d). We found little areas of clay loam or clay.

According to sensors "OptRx" tests, we composed a theoretical fertilization map (Fig. 4, a). The map shows that the highest fertilization rate (ammonium nitrate, 220 kg·ha^{-1}) should be performed in 22.6 % of the area, 200 kg·ha^{-1} in 24.8 %, 180 kg·ha^{-1} – 27.4 % and 160 kg·ha^{-1} – 25.2 %. Factual fertilizer distribution may be seen in Figure 4, b. Theoretical and factual maps are very similar, but the boundaries of PA field were fertilized in fewer rates than it is indicated.

The evaluation of spring wheat biometric and productivity parameters showed similar results in both agricultural systems (Table 2). CA indices were mainly higher than PA because the proportion of nutrients in CA field was higher than in PA.

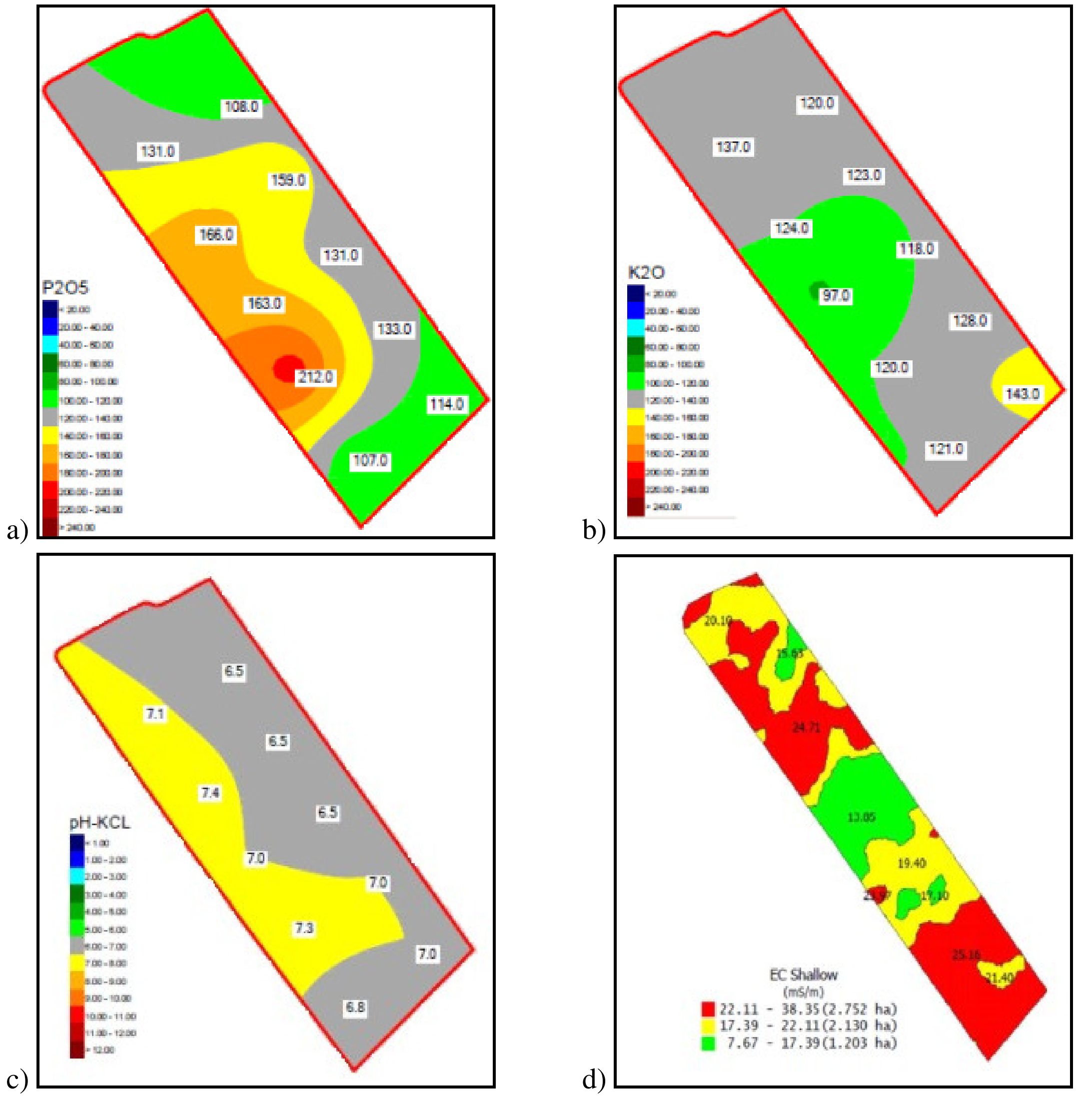

Fig. 3. **Distribution of viable phosphorus (P_2O_5) (a) and potassium (K_2O) (b), soil pH (c) and electrical conductivity (d) in the field of PA before beginning of the experiment**

In Vrindts et al. [14] experiment, soluble phosphate was a key soil parameter to predict the grain yield (coefficient of determination R^2 was 50-45). Crop reflection in May has strong correlation with the grain yield, especially near infrared reflectance (R^2 50-51).

Table 2

Biometric and productivity parameters of spring wheat crop

Index	Conventional agriculture	Precision agriculture
Number of productive stems, units m^{-2}	489	486
Height of plant, cm	63.9	63.1
Length of ear, cm	7.37	7.46
Number of grains in the ear, units	35.5	36.3
Mass of grains in one ear, g	1.57	1.63
Mass of 1000 grains, g	44.4	45.0
Number of productive stems, units m^{-2}	486	489
Yield of grain, t ha^{-1}	6.62	6.36

$p > 0.05$

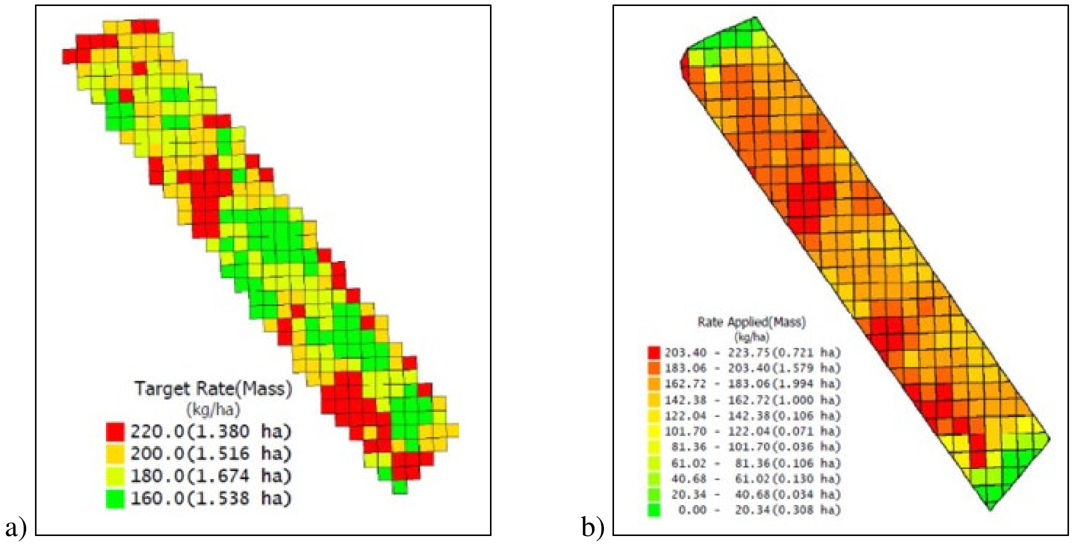

Fig. 4. **Theoretical map of PA field fertilization according to "OptRx" sensoring data (a); factual map of fertilizer distribution in the field (b)**

In both agricultural systems, the chemical composition of spring wheat grains was similar, too (Table 3).

Table 3

Chemical composition of spring wheat grains

Index	Conventional agriculture	Precision agriculture
Quantity of proteins, %	15.13 ± 0.058	14.70 ± 0.100
Quantity of wet gluten, %	28.7 ± 0.10	27.6 ± 0.31
Sedimentation index, mL	65.8 ± 0.31	64.3 ± 0.82
Moisture content, %	19.13 ± 0.058	18.60 ± 0.000

All the presented indices were higher in CA than in PA except the grain moisture content at the time of harvest. In CA conditions, the yield of grain, quantity of protein and gluten was by 3.9, 2.8 and 3.8 % grated than in PA. The differences of spring wheat productivity and quality mainly depended on higher proportion of available nutrients in CA soils.

Conclusions

1. The distribution of viable P in conditions of PA was uneven. On the average, the quantity of P was 142.4 mg·kg^{-1} and in CA – 151 mg·kg^{-1} or by 6 % higher.
2. In PA field, the quantity of viable K was distributed more evenly. In PA, the amount of K was on the average 123.1 mg·kg^{-1} and in CA – 160 mg·kg^{-1} or by 30 % higher. Variation of soil pH was from 6.5 to 7.4.
3. According to sensors "OptRx" tests, in CA conditions the spring wheat stand was higher developed than in PA. "OptRx" theoretical map showed that in PA the highest fertilization rate (ammonium nitrate, 220 kg·ha^{-1}) should be performed in 22.6 % of the area, 200 kg·ha^{-1} in 24.8 %, 180 kg·ha^{-1} – 27.4 % and 160 kg·ha^{-1} – 25.2 %.
4. In CA conditions, the mean yield of grains was 6.62 t ha^{-1} or by 3.9 % grater that in PA. Similarly, in CA, the quality of spring wheat grains was slightly better that in PA. The differences were affected by higher initial proportion of nutrients in CA.

Acknowledgement

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