ASSESSMENT OF ENERGY AND ENVIRONMENTAL IMPACT IN PRECISION SEEDING TECHNOLOGICAL PROCESSES

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Abstract. The technological process of seeding is very important in the production of cereals because seed germination, growth, yield and the qualitative parameters depend on the quality of seeding. Variable rate and variable depth precision seeding technology is relatively new and has many unanswered questions. The aim of this work was to investigate the influence of precision seeding of winter wheat according to a variable rate and variable depth on the grain yield, to evaluate different technological processes of seeding in terms of energy and environmental aspects, and to compare the obtained results with conventional seeding technology. Experimental research on growing winter wheat was carried out in 2021–2022. Precision seeding was performed using a variable rate seeding map generated from soil electrical conductivity data obtained by field surface scanning with the apparent soil electrical conductivity instrument EM-38 MK2 (Geonics Ltd, Canada). Three seeding technological processes were applied, the first variant was a uniform rate (URS, control), the second was a variable seeding rate (VRS), the third was a variable rate and variable depth (VRSD). Energy and environmental assessment were carried out using technological operations, fuel and material equivalents. The results of the experimental studies showed that the highest winter wheat grain yield (8744.08 $kg \cdot ha^{-1}$) was in the VRSD variant and it was about 6.5% higher compared to the conventional URS variant. The energy environmental analysis reported that the best energy and environmental efficiency results were achieved using the same VRSD technology, with the highest energy efficiency ratio (8.81) and the best GHG emission efficiency ratio (10.31), and the lowest environmental pollution per ton of winter wheat grain produced (56.24 kg CO_{2eq} t^{-1}).

Keywords: variable rate seeding, variable depth, soil management zone, energy efficiency, GHG emission.

Introduction

Winter wheat grain is a very important product in the general food chain. The growing demand for food in the world and limited land resources force us to look for new solutions to develop agricultural production more efficiently [1]. When moving to the application of precision agriculture, precision seeding becomes the main component of the modern agricultural plant seeding technology system, as an important means of saving production and resource costs and increasing efficiency. However, from the farmers' point of view, current seeding machines cannot always meet the accuracy requirements of winter wheat precision seeding [1].

It is believed that uniform seeding (URS) density may result in under- or over-optimal plant population, which may adversely affect the crop growth and yield [2]. Seed germination, crop development and plant yield may vary from field to field depending on soil variability. Therefore, to make better use of the soil's potential, precision seeding is increasingly being used, which, by applying a variable seed rate and variable sowing depth, allows seeding to be matched to the characteristics of the soil in the field and to ensure good plant productivity and economic benefits [3; 4].

To evaluate the variability of the soil in the easiest and cheapest way, the physical properties of the soil that can pass an electric current are usually considered. Soil apparent electrical conductivity (ECa) correlates with physical and chemical soil properties that affect the soil fertility and agricultural crop productivity [5].

Precision seeding technologies, applying site-specific seeding, can be one of the main technological solutions for adapting agroengineering processes to soil changes in the field, optimizing the seed rate to reflect field soil fertility. Authors [2], who conducted research on corn and applied variable rate seeding (VRS), found that precision seeding according to soil properties showed both yield increase and economic benefits compared to URS. The limited publication of the results of winter wheat seeding technologies from the point of view of precision seeding inspired experimental research in this topic. The aim of this work was to investigate the influence of precision seeding of winter wheat according to variable rate and variable depth on grain yield, to evaluate different technological processes of seeding in terms of energy and environmental aspects, and to compare the obtained results with conventional seeding.

Materials and methods

The research was carried out in 2021-2022 at a farmer's farm in the Panevėžys district of Lithuania. The area of the research field was 22.4 ha (55°40'27.7"N 24°08'43.9"E). Field soil electrical conductivity scans were performed at the beginning of the studies to determine the field soil variability. The apparent electrical conductivity (ECa) of the soil was measured with the scanner EM38 – MK2. Scanning was performed without contact with the soil, but by pulling the scanner along the surface of the field every 24 m between runs. ECa was measured in the 0-1.5 m soil layer.

Experimental studies of precision seeding of winter wheat were carried out according to 3 technological processes: the first – control, when seeding was done at a uniform rate and constant depth (URS), the second – seeding at a variable rate and constant depth (VRS), the third – seeding at a variable rate and variable depth (VRSD). Based on ECa of the field soil, the field was divided into 5 soil management zones (MZ). The third zone (MZ3) as moderate fertility soil with ECa ranging from 25.7 to 27.3 $mS \cdot m^{-1}$ was adopted as the middle zone, where the seeding rate was 162 $kg \cdot ha^{-1}$, seeding depth 3.0 cm. As soil fertility increased, the seeding rate and seeding depth were reduced, MZ2 – 10%, MZ1 – 20%, respectively. On the other hand, in poorer soils, the seeding rate and depth were increased, MZ4 – 10%, MZ5 – 20%, respectively. The soil texture of MZ1–MZ4 was sandy loam and that of MZ5 was loamy sand.

Seeding of winter wheat "Skagen" was carried out with a 6 m working width direct seeding seeder "Horsch Avatar 6.16 SD", which was additionally equipped with seeding depth support equipment (Fig. 1). Winter wheat was sown at 16.7 cm spacing, the seeding rate and depth were varied using a field map based on ECa.

Fig. 1. **Seeder with additional equipment for changing the seeding depth:** 1 – hydraulic hose; 2 – ISOBUS control module; 3 – hydraulic block; 4 – ISO standard connector; 5 – two-way hydraulic cylinders

All three seeding technological processes were performed in three replicates. To determine the yield of winter wheat, 5 crop samples were taken from each replicate before harvest. Winter wheat stalks were cut from a randomly selected 1.0 m long row of average plant density, which were threshed in the laboratory with a thresher Wintersteiger LD 350, and the winter wheat yield was calculated.

After determining the yield of winter wheat grains, an energetic and environmental evaluation was carried out. The same technological operations were used for all seeding technological processes, such as direct seeding into uncultivated soil, 5 fertilizations, 3 sprayings, harvesting and transportation to the grain store. The only difference was that the VRS and VRSD used variable rate seeding and variable depth maps, which were generated by ECa measurement and soil sampling while driving a Toyota Hilux in the field with the equipment installed. It was used for calculations that the average seeding rate was URS – 162.0 kg·ha^{-1}, VRS – 166.9 kg·ha^{-1}, VRSD – 162.2 kg·ha^{-1}, in all technological processes the rate of fertilizers, pesticides and growth regulators was the same, respectively nitrogen 180.0 kg·ha^{-1}, phosphorus 91.0 kg·ha^{-1}, potassium 54 kg·ha^{-1}, herbicides 0.02 kg·ha^{-1}, fungicides 1.55 kg·ha^{-1} and growth regulators 1.40 kg·ha^{-1}. The cost of human labour time, agricultural machinery and diesel fuel for different technological operations were calculated according to the literature [6,7].

Agricultural input and output equivalents needed for energy and environmental assessment calculations were used from the literature [8-19]. All equivalent values are given in Table 1.

Table 1

Energy and GHG emission equivalents of agricultural inputs and output

Input, output	Unit	Energy equivalents, MJ per unit	Reference	GHG emission equivalent, kg CO_{2eq} per unit	Reference
Human labour	h	1.96	[8]	0.36	[9]
Diesel fuel	L	39.6	[10]	2.76	[11]
Agricultural machinery (including self-propelled machines)	h	357.2	[12]	0.071	[13]
Winter wheat seeds	kg	20.1	[12]	0.58	[14]
N fertiliser	kg	40.0	[15]	1.3	[13]
P fertiliser	kg	15.8	[15]	0.2	[13]
K fertiliser	kg	9.3	[15]	0.15	[13]
Herbicides	kg	295.0	[16]	6.3	[17]
Fungicides	kg	115.0	[16]	3.9	[17]
Growth regulator	kg	10.0	[18]	4.7	[19]
Winter wheat grain yield	kg	14.48	[12]	0.58	[14]

To determine the energy efficiency of precision seeding of winter wheat, the energy efficiency ratio, energy productivity, net energy, and specific energy were calculated. The energy efficiency ratio shows the ratio between energy output and energy input, the energy productivity indicator shows how much winter wheat production can be produced with the consumption of one MJ of energy, the specific energy shows how much MJ of energy needs to be used to produce one kilogram of winter wheat grain, and finally the net energy shows the difference between energy output and energy input [8; 12].

The GHG emission efficiency ratio was determined when assessing the impact of winter wheat precision seeding technologies on the environment. Also, considering the publication of Alimagham et al. [20], the calculation of GHG emissions per kilogram of grain yield was applied.

Energy and environmental assessments were carried out using a usual calculation method, therefore, statistical analysis was performed only for the winter wheat yields determined by the experimental studies according to the technological processes. Tukey's method of statistical analysis was used to determine the significant difference at 95% probability. The same letters indicated that there was no significant difference between the technological processes.

Results and discussion

The energy balance of winter wheat production is very important in evaluating different technological operations. Fertilizers, seeds, and diesel fuel accounted for the largest part of energy consumption in all cases (Table 2). In this study, 3 different seeding technological operations were evaluated. The measured variability of soil ECa and the determined soil texture differed little across the field, except for the MZ5 zone, which had the poorest (sandier) soil composition. Therefore, the amount of seed used per hectare in VRS and VRSD was very close to the URS variant and did not have a significant impact on energy consumption when comparing between technological processes.

The yield of winter wheat grains had the greatest influence on the energy balance indicators. Although the yield difference between VRSD and VRS was about 959 kg·ha^{-1}, and between VRSD and URS – about 566 kg·ha^{-1}, statistical analysis showed that this difference between the technological processes was not significant (HSD_{05} = 1359.89 kg·ha^{-1}, according to Tukey method). The highest energy efficiency ratio (8.81) was achieved in the variant of precision seeding, in which seeding was done at a variable rate and variable depth. In this VRSD variant, other energy efficiency indicators were also the best, requiring the least MJ to produce one kilogram of winter wheat grain (1.64 MJ·kg^{-1}) and producing the most grain using one MJ of energy (0.61 kg MJ^{-1}).

Table 2

Indicators of energy assessment of conventional and precision seeding

Energy input, output	Unit	URS	VRS	VRSD
Human labour	MJ·ha^{-1}	1.60	1.72	1.74
Agricultural machinery	MJ·ha^{-1}	291.11	313.13	317.84
Diesel fuel	MJ·ha^{-1}	1437.69	1449.14	1459.84
Seeds	MJ·ha^{-1}	3256.20	3358.91	3261.02
N fertiliser	MJ·ha^{-1}	7200.00	7200.00	7200.00
P fertiliser	MJ·ha^{-1}	1437.80	1437.80	1437.80
K fertiliser	MJ·ha^{-1}	502.20	502.20	502.20
Herbicides	MJ·ha^{-1}	5.90	5.90	5.90
Fungicides	MJ·ha^{-1}	178.02	178.02	178.02
Growth regulator	MJ·ha^{-1}	14.00	14.00	14.00
Total (*energy input*)	MJ·ha^{-1}	14324.52	14457.00	14378.37
Winter wheat grain yield	kg·ha^{-1}	8178.58 a	7785.11 a	8744.08 a
Energy output				
Winter wheat	MJ·ha^{-1}	118425.89 a	112728.44 a	126614.28 a
Energy efficiency ratio	–	8.27	7.80	8.81
Specific energy	MJ·kg^{-1}	1.75	1.86	1.64
Energy productivity	kg MJ^{-1}	0.57	0.54	0.61
Net energy	MJ·ha^{-1}	104101.37	98271.44	112235.91

Notes: the same letters (a) mean that there is no significant difference between the seeding technological processes.

The agricultural sector is one of the most environmentally polluting production sectors [21]. Therefore, any technological means to reduce GHG emissions into the environment are acceptable. In this study, winter wheat production technology was evaluated, when seeding technological processes were changed. However, it is necessary to emphasize that no conventional tillage was used in this technology, but no-tillage technology was applied, and seeding was done on uncultivated soil. From this point of view, it is really a very environmentally friendly technology. The results published by other authors [21] showed that avoiding conventional tillage can reduce GHG emissions to the environment by up to 15%. Analyzing the environmental impact of conventional URS and precision VRS and VRSD seeding technologies, it was found that N fertilizers (about 48%), diesel fuel (about 20%) and seeds (about 19%) had the greatest influence on GHG emissions (Table 3).

Analyzing the total environmental impact results of seeding technologies, it was found that the non-significantly lowest GHG emissions of 488.17 kg CO_{2eq} ha^{-1} were in the conventional URS technological process, which did not require ECa measurements and did not require additional soil sampling equipment to create VRS and variable seeding depth maps. The best GHG emission efficiency ratio (10.31) was in VRSD, which showed the highest yield of winter wheat grain. This technological process of precision seeding with a variable rate and variable depth resulted in the lowest GHG emissions per ton of grain.

Economic aspects are always very important when analyzing technological processes in agriculture. Comparing the three seeding technological processes, it was found that the highest gross margin was obtained in VRSD, which was higher by about 5.9% compared to URS. A more detailed economic analysis of seeding technological processes can be found in the study [22].

Table 3

Environmental assessment indicators of conventional and precision seeding

GHG input, output	Unit	URS	VRS	VRSD
Human labour	kg CO_{2eq} ha^{-1}	0.29	0.32	0.32
Agricultural machinery	kg CO_{2eq} ha^{-1}	20.67	22.23	22.57
Diesel fuel	kg CO_{2eq} ha^{-1}	100.20	101.00	101.75
Seeds	kg CO_{2eq} ha^{-1}	93.96	96.92	94.10
N fertiliser	kg CO_{2eq} ha^{-1}	234.00	234.00	234.00
P fertiliser	kg CO_{2eq} ha^{-1}	18.20	18.20	18.20
K fertiliser	kg CO_{2eq} ha^{-1}	8.10	8.10	8.10
Herbicides	kg CO_{2eq} ha^{-1}	0.13	0.13	0.13
Fungicides	kg CO_{2eq} ha^{-1}	6.04	6.04	6.04
Growth regulator	kg CO_{2eq} ha^{-1}	6.58	6.58	6.58
Total (*GHG input*)	kg CO_{2eq} ha^{-1}	488.17	493.52	491.78
Winter wheat grain yield	kg·ha^{-1}	8178.58 a	7785.11 a	8744.08 a
GHG output				
Winter wheat	kg CO_{2eq} ha^{-1}	4743.58 a	4515.37 a	5071.57 a
GHG emission efficiency ratio	–	9.72	9.15	10.31
GHG emission per weight	kg CO_{2eq} t^{-1}	59.69	63.39	56.24

Notes: the same letters (a) mean that there is no significant difference between the seeding technological processes.

Conclusions

1. The application of different seeding technological processes in the production of winter wheat showed that the highest grain yield (8744.08 kg·ha^{-1}) was in VRSD, when a variable seeding rate and variable seeding depth were applied. The grain yield was about 6.5% higher compared to conventional URS.
2. The lowest energy consumption of winter wheat production was in URS (14324.52 MJ·ha^{-1}), but due to the higher yield, the energy efficiency ratio was the highest in VRSD (8.81). The indicators of energy productivity and specific energy were also the best in VRSD, 0.61 kg·MJ^{-1} and 1.64 MJ·kg^{-1}, respectively.
3. The results of the GHG emission analysis showed that there was no significant difference in the total cost of GHG emissions between the seeding technological processes. The best indicators of GHG emission efficiency ratio and GHG emission per ton of winter wheat grain were demonstrated by VRSD, 10.31 and 56.24 kg CO_{2eq} t^{-1}, respectively.
4. The highest gross margin was achieved by applying the VRSD technological process. Compared to conventional URS, the gross margin in VRSD was about 5.9% higher.

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Author contributions

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