THE AGRONOMIC AND BIOECONOMIC ASPECTS OF SITE-SPECIFIC SEEDING RATES AND DEPTHS FOR WINTER WHEAT IN LITHUANIA

Kriauciuniene Z, Kazlauskas M, Romaneckas K, Buragiene S, Bruciene I, Sarauskis E

Vytautas Magnus University Agriculture Academy, Lithuania

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Abstract. *Precision seeding is a key agrotechnological solution for smart agriculture because it enables crop establishment to be adapted to within-field soil variability. The objective of this study was to evaluate the agronomic and bioeconomic effects of site-specific seeding (SSS) rates and variable SSS depth for winter wheat under Lithuanian conditions, with comparison against conventional uniform-rate seeding (URS). Field experiments were conducted in a 22.4 ha commercial field in Panevezys district, Lithuania. Soil apparent electrical conductivity (ECa) was measured with an EM38-MK2 electromagnetic induction sensor, and the field was divided into five management zones (MZs). MZ1 had the highest ECa and greatest relative productivity potential, whereas MZ5 had the lowest ECa, the lightest soil texture, and the lowest relative productivity potential. URS applied 180 kg ha*$^{-1}$ *across all MZs. SSS used a Robin Hood strategy, decreasing the seeding rate in more productive zones and increasing it in lower-productivity zones, with rates from 146 kg ha*$^{-1}$ *in MZ1 to 214 kg ha*$^{-1}$ *in MZ5. A related seeding-depth experiment compared uniform seeding depth with variable one across the same ECa-derived zones. Yield components, grain yield, and a partial bioeconomic analysis were used to assess performance. SSS increased mean grain yield from 7237 to 7805 kg ha*$^{-1}$*, or by 7.85%. Yield increased under SSS in four of five MZs; the greatest relative increase occurred in MZ5 (+13.43%), followed by MZ2 (+12.13%). Ears, grains per ear, and 1000-grain weight were also higher under SSS. Gross margin increased from 1670.23 to 1808.78 Eur ha*$^{-1}$*, an 8.30% increase compared with URS. In the depth experiment, variable SSS depth produced about 321 kg ha*$^{-1}$ *more grain than uniform-depth seeding on average, although the effect was not statistically significant. The results demonstrate that ECa-based MZs can guide winter wheat seeding-rate and seed-placement decisions in heterogeneous Lithuanian fields. Further multi-site and multi-year validation is needed before broad recommendations are made.*

Keywords. *apparent electrical conductivity; bioeconomics; management zones; precision agriculture; seeding depth; site-specific seeding; variable-rate seeding; Triticum aestivum L.*

Introduction

Winter wheat is one of the most important arable crops in Lithuania and Europe. Its productivity is strongly affected by spatial variation in soil texture, water-holding capacity, nutrient availability, and crop establishment conditions. Conventional seeding usually applies one seed rate and one target depth across an entire field. Although this approach is simple, it does not account for the fact that sandy or low-fertility zones may require a different plant population than heavier or more productive zones.

Precision agriculture provides tools to convert within-field variability into management decisions. Soil apparent electrical conductivity (ECa) is widely used to identify management zones (MZs) because it is related to soil texture, water content, salinity, organic matter, and other properties that influence crop establishment (Fulton 2019). Site-specific seeding (SSS) adjusts seeding rate according to zone-specific productivity potential. SSS depth is also relevant because soil physical properties can influence seed placement, emergence, and stand uniformity (Romaneckas et al. 2023).

The objective of this study was to assess the effects of site-specific seeding rates and depth on winter wheat productivity and profitability in Lithuania compared with conventional uniform-rate (URS) seeding practices.

Materials and Methods

Experimental site and management-zone delineation

The seeding-rate experiment was conducted during the 2020–2021 growing season in a 22.4 ha commercial field in Panevezys district, Lithuania (55°40′27.7″N 24°08′43.9″E). Soil ECa was measured in the 0–1.5 m soil layer using an EM38-MK2 electromagnetic induction sensor (Geonics Ltd, Mississauga, Canada). The sensor was pulled on plastic sleds behind a Toyota Hilux vehicle equipped with a Trimble EZ-Guide 250 global positioning system receiver (Trimble Inc., Sunnyvale, USA). Measurements were collected along 24 m tramlines and processed in QGIS to delineate five MZs.

MZ1 had the highest ECa and the highest relative productivity potential. MZ5 had the lowest ECa, highest sand content, and lowest relative productivity potential. The seeding-rate treatments were therefore designed to reduce seed input in high-productivity zones and increase seed input in low-productivity zones.

Table 1 shows that the SSS treatment ranged from 146 kg ha^{-1} in the highest-productivity zone to 214 kg ha^{-1} in the lowest-productivity zone, while URS remained constant at 180 kg ha^{-1}.

Table 1. Soil management zones and seeding rates used in the URS and SSS treatments

MZ	ECa, mS m^{-1}	Sand, %	Silt, %	Clay, %	Relative fertility	URS, kg ha^{-1}	SSS, kg ha^{-1}
MZ1	>28.6	60.8	24.4	14.8	Highest	180	146
MZ2	27.3–28.6	73.3	17.4	9.3	Medium-high	180	153
MZ3	25.7–27.3	69.0	19.4	11.6	Medium	180	180
MZ4	24.2–25.7	70.6	18.7	10.7	Medium-low	180	197
MZ5	22.6–24.2	81.4	12.0	6.6	Lowest	180	214

The soil ECa map (Fig. 1) was produced from the field soil scanning and clearly showed that the largest part of the field (36 %) was ECa, which varied between 25.7 and 27.3 mS m^{-1}.

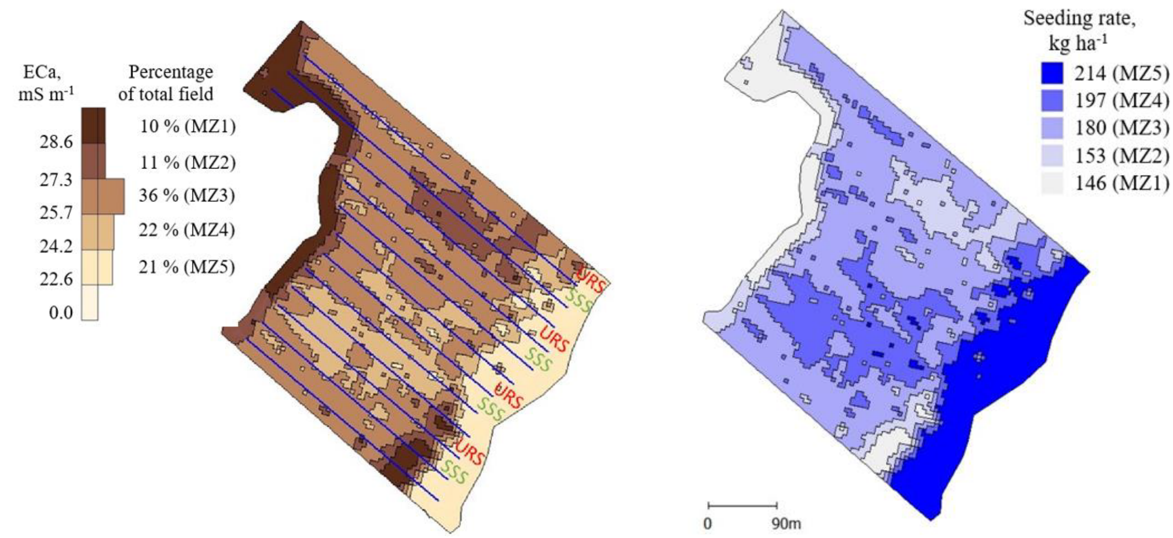

Fig 1. Maps of the apparent electrical conductivity (ECa – left) and site-specific seeding recommended rate (right) of the experimental field soil: URS – uniform rate seeding; SSS – site-specific seeding (from Kazlauskas, 2024).

Seeding-rate treatments and measurements

Winter wheat (*Triticum aestivum* L., cv. Skagen) was sown on 15 September 2020 after peas, without soil tillage. A Horsch Avatar 6.16 SD direct drill (Horsch Maschinen GmbH, Schwandorf, Germany) with 6 m working width, 167 mm row spacing, 30 mm target seeding depth, and 10 km h^{-1} operating speed was used. URS applied 180 kg ha^{-1} throughout the field. SSS applied 146, 153, 180, 197, and 214 kg ha^{-1} in MZ1 to MZ5, respectively, following the Robin Hood principle of reducing seed rate in zones with higher productivity potential and increasing seed rate in zones with lower productivity potential (Sarauskis et al. 2023).

Winter wheat samples were collected at harvest from 40 locations, with five samples taken from each URS and SSS replicate. Plants were cut from 1 m of row and threshed using a Wintersteiger LD 350 laboratory combine (Wintersteiger AG, Ried im Innkreis, Austria). Grain mass was weighed using a Kern KB 3600-2N laboratory balance (Kern and Sohn GmbH, Balingen, Germany), recalculated to kg ha^{-1}, and standardized to equal grain moisture. Plant height, straw-to-grain ratio, ears m^{-2}, grains per ear, 1000-grain weight, grain protein content, and grain yield were assessed.

A partial bioeconomic analysis was performed using a wheat grain price of 240 Eur t^{-1} and seed cost of 370 Eur t^{-1}. Gross margin was calculated as grain revenue minus seed cost. Fuel, crop protection, machinery, and labor costs were excluded because they were similar between methods in this experiment.

Variable seeding-depth experiment

The seeding-depth experiment was conducted during the 2021–2022 growing season in the same field. Uniform seeding depth was compared with SSS. The DepthXControl hydraulic system (Geoprospectors GmbH, Traiskirchen, Austria) was mounted on the Horsch Avatar 6.16 SD drill. A variable-depth map based on ECa was loaded into a TOUCH 1200 terminal (Muller-Elektronik GmbH, Salzkotten, Germany). According to drill position and the depth map, the system adjusted hydraulic pressure and coulter downforce. Actual seed depth was measured from the soil surface to the seed furrow with a metal ruler.

Results and Discussion

Yield components under SSS

SSS improved mean values of the main yield components compared with URS. On average ears increased from 577.4 to 595.7 m^{-2}, grains per ear increased from 35.45 to 36.34, and mean 1000-grain weight increased from 33.77 to 35.28 g. As shown in Table 2, the response was zone-specific. In MZ5, which had the lightest soil texture and lowest ECa, grains per ear increased from 28.59 under URS to 34.44 under SSS, and 1000-grain weight increased from 28.59 to 33.86 g. These results indicate that a higher seed rate in the least productive zone compensated partly for weaker crop establishment and yield formation.

Table 2. Yield component responses to URS and SSS across management zones

MZ	Ears URS, m^{-2}	Ears SSS, m^{-2}	Grains ear^{-1} URS	Grains ear^{-1} SSS	1000-grain URS, g	1000-grain SSS, g
MZ1	516.0	519.0	36.86	35.68	34.81	35.68
MZ2	602.0	639.0	37.96	39.01	34.27	35.72
MZ3	607.0	632.6	36.14	36.07	35.26	33.72
MZ4	609.4	642.0	37.72	36.51	35.95	37.44
MZ5	552.0	546.0	28.59	34.44	28.59	33.86
Mean	577.4	595.7	35.45	36.34	33.77	35.28
LSD_{05}	38.73	40.02	1.31	0.90	1.68	1.39
LSD_{05} (URS×SSS)	38.93		38.93		38.93	

Grain yield response

The average grain yield under URS was 7237 kg ha^{-1}, whereas SSS produced 7805 kg ha^{-1}. The mean yield advantage was therefore 568 kg ha^{-1}, or 7.85%. Yield increased under SSS in four of five MZs (Table 3). The largest relative increases occurred in MZ5 (+13.43%) and MZ2 (+12.13%). MZ3 was the only zone where SSS did not increase yield; this was expected because both methods used the same seed rate in this zone. These results support the concept that seed should be redistributed according to soil productivity rather than applied at a single field-average rate.

Table 3. Winter wheat grain yield by management zone and seeding method

MZ	URS yield, kg ha^{-1}	SSS yield, kg ha^{-1}	Difference, %
MZ1	6621	7325	10.63
MZ2	7893	8851	12.13
MZ3	7775	7715	-0.77
MZ4	8272	8756	5.85
MZ5	5623	6378	13.43
Mean	7237	7805	7.85
LSD_{05}	808	609	-
LSD_{05} (URS× SSS)	705		-

Bioeconomic performance

The economic response followed the yield response. Mean revenue increased from 1736.83 Eur ha^{-1} under URS to 1874.64 Eur ha^{-1} under SSS. Mean seed cost was almost unchanged at the field scale because lower rates in high-productivity zones offset higher rates in low-productivity zones. As shown in Table 4, gross margin increased from 1670.23 to 1808.78 Eur ha^{-1}, a gain of 138.55 Eur ha^{-1} or 8.30%. The result shows that the economic benefit resulted mainly from higher yield rather than from seed saving alone.

Table 4. Summary of partial economic analysis for URS and SSS

Method	Seeding cost, Eur ha^{-1}	Yield, t ha^{-1}	Revenue, Eur ha^{-1}	Gross margin, Eur ha^{-1}	Change vs. URS, %
URS	66.60	7.237	1736.83	1670.23	-
SSS	65.86	7.810	1874.64	1808.78	8.30

Note: the average market price of winter wheat seed used for the calculations was €370 t^{-1} (2020); The average market price of the winter wheat grain yield was €240 t^{-1} (2021).

Variable seeding-depth response

In the seeding-depth experiment, the average measured depth was 31.10 mm under uniform-depth seeding and 29.48 mm under variable SSS depth. The main method effect on measured depth and yield was not statistically significant, but practical differences were observed among zones. Table 5 shows that mean grain yield was 8422.6 kg ha⁻¹ under uniform-depth seeding and 8744.1 kg ha⁻¹ under variable SSS depth, an increase of about 321.5 kg ha⁻¹. The largest practical response occurred in MZ5, where yield increased from 6231.2 to 7957.8 kg ha⁻¹. This suggests that lighter soils and lower ECa zones may be more sensitive to seed placement and coulter downforce decisions, although additional studies are needed to confirm the response.

Table 5. Seeding depth and grain yield in the 2021-2022 experiment

MZ	Depth URS (A), mm	Depth SSS (A), mm	Depth mean (B), mm	Yield URS (A), kg ha⁻¹	Yield SSS (A), kg ha⁻¹	Yield mean (B), kg ha⁻¹
MZ1	33.17	30.05	31.61	8643.2	8669.2	8656.2
MZ2	29.38	27.74	28.56	9499.0	9111.0	9305.0
MZ3	29.88	27.76	28.82	8832.8	8606.6	8719.7
MZ4	30.86	28.71	29.79	8906.6	9375.8	9141.2
MZ5	32.21	33.12	32.67	6231.2	7957.8	7094.5
Mean (A)	31.10	29.48	-	8422.6	8744.1	-
Interaction A × B *F-act.* 0.51, $p > 0.05$, LSD_{05}–4.445				Interaction A × B *F-act.* 0.51, $p > 0.05$, LSD_{05}–2502.1		

Agronomic implications

The combined results show that ECa-based zoning can support both seed-rate and seed-placement decisions. The practical value of SSS is more efficient seed redistribution: lower rates in more fertile zones reduce excessive crop competition, while higher rates in less fertile zones improve establishment and yield formation. The economic advantage was achieved without an increase in mean seed cost, which is important for adoption by commercial farms. The variable SSS depth results were promising but should be interpreted as supporting evidence because the method effect was not statistically significant. The greatest return from precision seeding is expected in heterogeneous fields where soil properties vary sufficiently to justify zone-specific management.

Conclusions

ECa-based MZs provided a practical framework for adapting winter wheat seeding rates to within-field soil variability. SSS increased average grain yield from 7237 to 7805 kg ha⁻¹, a 7.85% increase compared with URS. The strongest yield response occurred in low-productivity MZ5, where SSS increased grain yield by 13.43%. Gross margin increased by 138.55 Eur ha⁻¹, or 8.30%, under SSS compared with URS. Variable SSS depth produced about 321 kg ha⁻¹ more grain than uniform-depth seeding on average, with the largest practical response in MZ5, but the effect was not statistically significant. Further multi-year and multi-site research is needed to validate these results under different soil-variability and weather conditions.

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References

Fulton, J. (2019). Variable-rate seeding systems for precision agriculture. In Precision Agriculture for Sustainability; Stafford, J., Ed.; Burleigh Dodds Science Publishing Limited, Silsoe Solutions: Cambridge, UK, 2019; pp. 28–297.

Kazlauskas, M. (2024). Assessing the impact of precision seeding and fertilization methods on winter wheat and the environment. Doctoral dissertation, Vytautas Magnus University, Kaunas, Lithuania.

Romaneckas, K., Buragiene, S., Kazlauskas, M., Steponavicius, D., Naujokiene, V., Bruciene, I., & Šarauskis, E. (2023). Effects of soil electrical conductivity and physical properties on seeding depth maintenance and winter wheat germination, development and productivity. Agronomy, 13(1), 190.

Sarauskis, E., Kazlauskas, M., Bruciene, I., Naujokiene, V., Romaneckas, K., Buragiene, S., Steponavičius D. & Mouazen, A. M. (2023). Impact of soil electrical conductivity-based site-specific seeding and uniform rate seeding methods on winter wheat yield parameters and economic benefits. Precision Agriculture, 24, 2438–2455.