A seeder for sustainable agriculture enabling intercropping and multi-variety sowing and adaptable to precision agriculture through variable-rate seeding

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Abstract.

Adapting agricultural systems to climate change while improving resource-use efficiency requires flexible and scalable seeding technologies compatible with precision agriculture. Variable-rate seeding combined with intercropping and multi-variety sowing can enhance biodiversity, optimize resource use, and improve yield stability. However, adoption remains limited due to the lack of affordable machinery capable of independently controlling sowing parameters across multiple crops or varieties. This paper presents a newly developed modular seeder enabling intercropping and multi-variety sowing, adaptable to precision agriculture through variable-rate seeding. Each row unit is independently controlled and equipped with a vertical-disc metering mechanism driven by an electric servo motor, allowing software-based adjustment of seeding rate and spacing. The system supports intercropping (simultaneous sowing of different crops in adjacent rows) and multi-variety sowing (alternating varieties within a row). Real-time ground-speed feedback ensures consistent seed spacing under variable speeds and compatibility with prescription-based applications. The compact design enables narrow inter-row spacing, while the scalable toolbar supports different farm sizes. The chassis allows both trailed and three-point hitch configurations. Experimental validation under controlled and field conditions showed good seed distribution. The coefficient of variation (CV) of seed spacing was below 20% (maximum 18%), indicating uniform spacing, while the seeding depth CV ranged between 15–20% (below 25%), confirming consistent depth placement. The design combines modularity, independent control, and narrow-row capability. These results confirm its suitability for precision agriculture applications involving intercropping and multi-variety sowing under variable-rate seeding. The study was conducted within a Lithuanian Research Council–supported project (Design, Development, and Evaluation of a Seeder Prototype for Intercropping, Multi-Variety, or Multi-Hybrid Systems at Variable Sowing Rates), including ongoing evaluation under controlled and field conditions.

Keywords.
Variable-rate seeding; intercropping; multi-variety seeding; seed metering, pea, caraway

Introduction

Climate change, increasing input costs, and the need to improve resource-use efficiency require seeding technologies that can support more flexible and site-specific crop establishment strategies. Precision agriculture aims to optimize crop management by accounting for spatial field variability and applying inputs according to local crop and soil requirements (Georgi et al., 2017). In this context, variable-rate seeding (VRS) has become an important precision agriculture approach because it allows the seeding rate to be adjusted according to soil properties, terrain, yield potential, and other spatially variable field conditions (Šarauskis et al., 2022). Such systems can improve seed-use efficiency and support more targeted crop establishment compared with conventional constant-rate sowing.

Recent developments in planter technology have made VRS more practical through hydraulic, electric, or independently controlled metering systems. Virk et al. (2019) reported that modern row-crop planters can support variable-rate seeding, but planter performance remains strongly related to meter speed, seed spacing, and machine settings. Balafoutis et al. (2017) also emphasized that advanced precision seeding systems may require independent row control and prescription maps to adjust seeding rates on the go. Therefore, the development of seeders with row-level control is essential for translating precision agriculture data into practical field operations.

In addition to variable-rate seeding, intercropping and multi-variety or multi-hybrid sowing are increasingly relevant for sustainable agriculture. Intercropping can improve resource-use efficiency, biodiversity, land productivity, and production stability compared with sole cropping systems (Weih et al., 2022). However, practical adoption requires machinery capable of sowing different crops or varieties at different rates and spatial arrangements. Multi-hybrid and multi-variety planting technologies have been proposed to match crop genetics with field variability, but they require separate seed delivery systems and adapted metering mechanisms (Balafoutis et al., 2017; Corassa et al., 2018).

Seed placement quality is another critical requirement for such systems. Uniform seed spacing and depth influence crop emergence, stand establishment, and yield potential. Siemens and Gayler (2016) noted that coefficient of variation, skips, multiples, and precision indices are commonly used to evaluate planter performance. Thus, a seeder intended for intercropping, multi-variety sowing, and variable-rate operation must combine agronomic flexibility with accurate seed metering and placement.

Based on these requirements, this study presents a newly developed modular seeder designed for sustainable and precision agriculture applications. The system enables intercropping, multi-variety sowing, and variable-rate seeding through independently controlled row units equipped with electrically driven vertical-disc metering mechanisms. The objective of this proceeding is to describe the design concept and evaluate the preliminary performance of the prototype under controlled and field conditions.

Materials and Methods

Seeder prototype design

A modular seeder prototype capable of intercropping, multi-variety sowing, and variable-rate seeding was developed within the framework of the Lithuanian Research Council–supported project entitled *“Design, Development, and Evaluation of a Seeder Prototype for Intercropping, Multi-Variety, or Multi-Hybrid Systems at Variable Sowing Rates”*. The prototype was designed to independently control two seed metering systems and to enable flexible sowing configurations according to crop type and field management requirements.

The seeder consisted of independently operated row units equipped with vertical-disc seed metering mechanisms driven by brushless DC electric servo motors. Each metering disc was controlled separately through an electronic drive system that adjusted the rotational speed of the disc according to the desired seeding rate and forward speed. The chassis of the seeder was designed to support both trailed and three-point hitch configurations, while narrow row spacing was maintained to increase adaptability for intercropping applications.

The electronic control system consisted of three main components: (i) a control panel for entering target seed spacing and selecting active seed metering units, (ii) a processor integrated with speed and rotational sensors, and (iii) motor drivers and electric motors controlling the metering discs. Real-time ground-speed feedback was used to synchronize seed release with machine travel speed and to maintain consistent seed spacing under varying operating conditions (Figure 1).

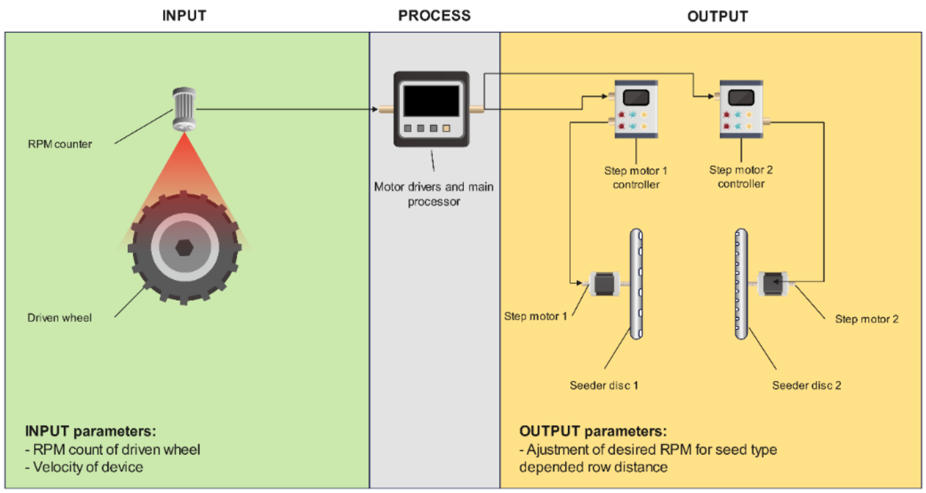


Figure 1. The electronic drive system of the seeder prototype

Seeder configuration for intercropping and multi-variety sowing

Two different sowing configurations were evaluated: intercropping sowing and multi-variety sowing (Figures 2 - 4).

For intercropping sowing, pea (*Pisum sativum* L.) and caraway (*Carum carvi* L.) seeds were used simultaneously. Pea seeds were supplied from one hopper and caraway seeds from the second hopper. The two seed metering systems operated independently, and both crops were sown simultaneously in adjacent rows during a single field pass.

For multi-variety sowing, two different pea varieties were used. In this configuration, the two seed tubes were merged into a single seed tube connected to one furrow opener. One seed metering unit remained active while the second stayed in standby mode. The electronic control system automatically switched between the two seed metering systems during operation, allowing sequential sowing of different pea varieties within the same row. The switching performance between varieties was also evaluated.

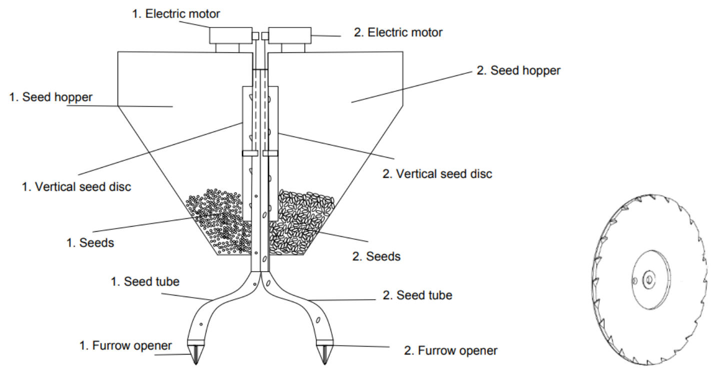


Figure 2. Schematic view for the arrangement of seeder prototype for intercropping and vertical seed metering disc

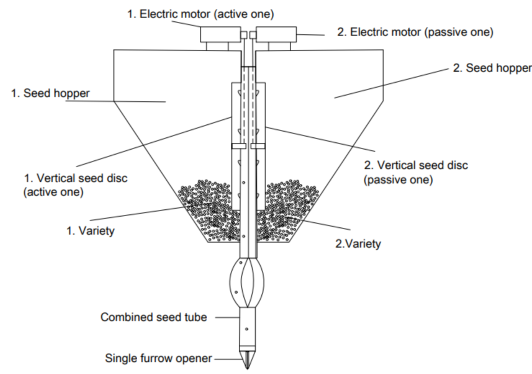
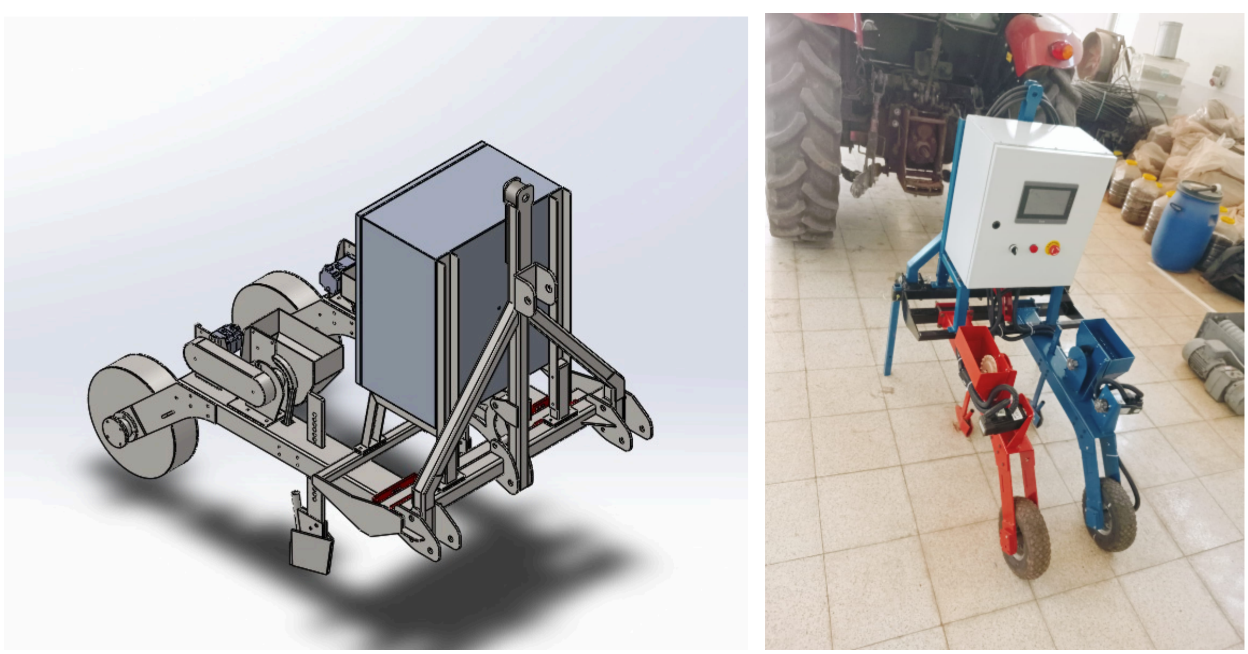


Figure 3. Schematic view for the arrangement of seeder prototype for multi-variety sowing



(a) (b)

Figure 4. (a) Three-dimensional CAD model and (b) photograph of the developed seeder prototype

Laboratory experiments

Laboratory tests were conducted using a seeder test bench (Figure 5). The experiments were carried out under controlled conditions to evaluate the seeding performance of the developed prototype.

The seeder prototype was tested at forward speeds ranging from 5 to 7 km h^{-1}. During the experiments, seed spacing uniformity and switching efficiency (for multi-variety sowing only) were evaluated. Seed distribution characteristics were determined according to the methodology described by Karayel et al. (2006). Furthermore, the coefficient of variation (CV) of seed spacing was calculated according to ISO 7256/2 standards to assess sowing uniformity and the precision performance of the seeder prototype.

For the multi-variety sowing configuration, the switching efficiency between the two pea varieties was evaluated by analyzing seed spacing continuity within the transition zone during switching between active and standby metering units.

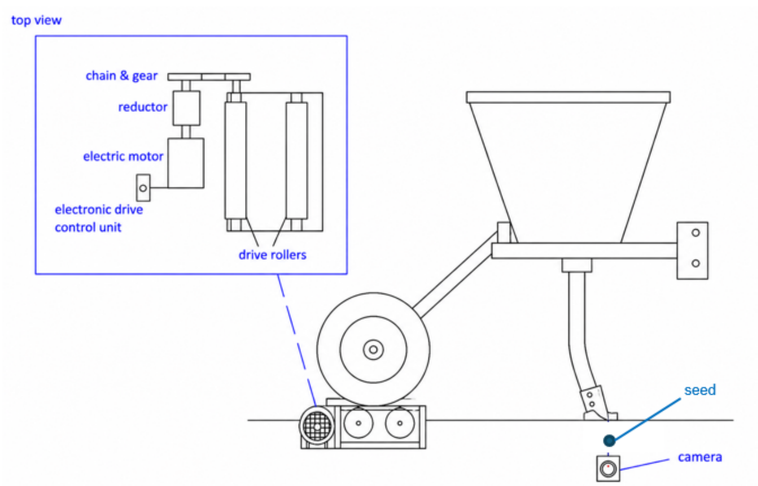


Figure 5. Seeder test bench

Field experiments

Separate experiments were performed for intercropping and multi-variety sowing applications for field trials. The seeder prototype was tested at forward speeds between 5 and 7 km h^{-1} using a shoe-type furrow opener. Both experiments were replicated under different sowing rates to evaluate the adaptability of the variable-rate seeding system.

For intercropping trials, pea and caraway seeds were simultaneously sown in adjacent rows. For multi-variety sowing trials, the electronic system alternated between two pea varieties during sowing operations to evaluate the switching efficiency and precision of the system.

Field performance was evaluated using seed spacing uniformity and sowing depth uniformity parameters according to ISO 7256/1 standards and related methodologies reported in previous studies. The coefficient of variation of seed spacing and sowing depth was calculated to assess the precision of the seeding operation. In addition, switching efficiency between seed varieties was evaluated during multi-variety sowing experiments. Field performance measurements were conducted based on emerged seedlings in order to evaluate the actual establishment performance of the sowing system under field conditions.

Switching efficiency evaluation

For multi-variety sowing experiments, the switching efficiency of the seeding system between the two pea varieties was evaluated by analysing seed spacing continuity during the transition between varieties. During operation, one seed metering unit was active while the second remained in standby mode, and the electronic control system automatically switched between the two metering units according to the predefined sowing sequence.

To evaluate switching performance, a control zone corresponding to ten nominal seed spacings was defined around each switching point. This zone consisted of five nominal seed spacings before the switching point and five nominal seed spacings after the switching point. The actual seed spacings within this transition zone were measured after sowing.

The measured spacings were classified according to ISO precision seeding criteria. Seed spacings within the range of $0.5Z < X < 1.5Z$ were considered successful spacings, where (Z) is the nominal seed spacing and (X) is the measured spacing between consecutive seeds. The number of successful spacings within the transition zone was recorded and used to determine the switching efficiency of the system.

The switching efficiency (SE) was calculated as:

$$SE\ (\%) = (N_s / N_t) \times 100 \tag{1}$$

where (N_s) is the number of successful seed spacings within the transition zone and (N_t) is the total number of measured spacings in the transition zone.

The switching efficiency was evaluated at forward speeds of 5, 6, and 7 km h^{-1}. Higher switching efficiency values indicated more stable and accurate transitions between the two seed varieties with minimal disturbance in seed distribution uniformity.

Results and Discussion

Laboratory performance of the seeder prototype

The laboratory experiments demonstrated that the developed seeder prototype provided stable seed metering performance for both intercropping and multi-variety sowing configurations. The independently controlled electric metering units maintained acceptable seed distribution uniformity and switching performance at different forward speeds.

The laboratory performance indicators obtained for intercropping sowing using pea and caraway seeds and for multi-variety sowing are presented in Table 1.

Table 1. Laboratory performance indicators of the seeder prototype

Application	Forward speed (km h^{-1})	Seed spacing CV (%)	Switching efficiency, SE (%)
Pea	5	10.8	-
Pea	6	13.2	-
Pea	7	15.4	-
Caraway	5	12.1	-
Caraway	6	14.8	-
Caraway	7	16.9	-
Multi-variety pea sowing	5	11.2	92.8
Multi-variety pea sowing	6	13.7	91.4
Multi-variety pea sowing	7	15.9	90.9

The laboratory results showed that seed spacing variability increased with increasing forward speed for all treatments. However, the coefficient of variation remained below 20% in all cases, indicating acceptable seed metering precision. Pea seeds generally produced lower spacing variability than caraway seeds because of their larger size and more stable interaction with the vertical-disc metering mechanism. The multi-variety sowing experiments demonstrated high switching efficiency between the two pea varieties. Switching efficiency values exceeded 90% under all forward speed conditions, indicating that the electronic control system successfully managed the transition between active and standby metering units with minimal disturbance in seed spacing distribution.

Field performance of the seeder prototype

Field experiments confirmed the operational capability of the seeder under real agricultural conditions. The system successfully performed both intercropping and multi-variety sowing operations while maintaining acceptable sowing quality and switching performance. The field performance indicators are presented in Table 2.

Table 2. Field performance indicators of the seeder prototype

Application	Forward speed (km h^{-1})	Seed spacing CV (%)	Sowing depth CV (%)	Switching efficiency (%)
Intercropping (pea + caraway)	5	12.4	15.2	-
Intercropping (pea + caraway)	6	15.7	17.8	-
Intercropping (pea + caraway)	7	18.0	19.6	-
Multi-variety pea sowing	5	11.8	15.0	91.5
Multi-variety pea sowing	6	14.9	17.1	91.2
Multi-variety pea sowing	7	17.3	19.4	90.8

The field results demonstrated that the seeder maintained acceptable sowing performance under different operating conditions. Seed spacing coefficient of variation values remained below 20% for all treatments, while sowing depth variation remained below 25%. Similar to laboratory experiments, spacing variability increased slightly at higher forward speeds because of increased vibration and seed movement dynamics within the seed tube and furrow area.

The obtained results are consistent with previous studies reporting that planter performance is strongly influenced by operating speed and seed metering characteristics. Virk et al. (2019) reported that increasing meter speed may increase plant spacing variability during variable-rate seeding applications. Similarly, Siemens and Gayler (2016) indicated that higher travel speeds may negatively affect seed placement precision because of seed bounce and rolling within the furrow. In the present study, although spacing variability increased slightly with forward speed, the obtained values remained within acceptable limits for precision seeding applications.

The independently controlled metering units also demonstrated advantages for intercropping and multi-variety sowing systems. Intercropping systems are known to improve biodiversity, resource-use efficiency, and production stability compared with monocropping systems. Weih et al. (2022) emphasized that intercropping contributes to sustainable agriculture through more efficient utilization of environmental resources. The developed prototype successfully enabled simultaneous sowing of pea and caraway seeds in adjacent rows during a single field pass, demonstrating its practical suitability for intercropping systems.

The developed seeder also showed strong potential for precision agriculture applications. The prototype maintained accurate seed placement performance under different forward speeds while the electronic control system successfully responded to operational commands and automatically adjusted the metering units according to travel speed and target sowing conditions. Furthermore, the independently controlled row units enabled separate management of different crops and seed varieties during sowing operations. The high switching efficiency values confirmed the ability of the system to accurately control transitions between seed varieties with minimal disturbance in seed spacing. These results indicate that the developed prototype can support precision agriculture applications involving electronically controlled variable-rate seeding, intercropping, and multi-variety sowing under varying operational conditions.

Conclusions

This study presented the design and preliminary evaluation of a modular seeder prototype developed for sustainable and precision agriculture applications. The developed system enabled intercropping, multi-variety sowing, and variable-rate seeding through independently controlled row units equipped with electrically driven vertical-disc metering mechanisms. The electronic control system, supported by real-time ground-speed feedback, allowed accurate synchronization between machine travel speed and seed release, providing stable seed spacing under varying operating conditions.

Both laboratory and field experiments confirmed the operational capability of the developed prototype. The coefficient of variation of seed spacing remained below 20% under all tested conditions, while sowing depth variation in field conditions remained below 25%, indicating acceptable sowing quality and placement uniformity. The multi-variety sowing configuration also demonstrated high switching efficiency between seed varieties, exceeding 90% in field conditions and confirming the ability of the electronic control system to manage transitions between metering units with minimal disturbance to seed distribution.

The developed seeder demonstrated strong adaptability for sustainable cropping systems by enabling simultaneous sowing of different crops and controlled switching between varieties within the same row. The modular structure, independently controlled metering units, narrow-row capability, and scalable chassis design provide flexibility for different farm sizes and cropping strategies. Furthermore, the integration of electrically driven metering systems and variable-rate control indicates strong potential for future precision agriculture applications using prescription maps and site-specific crop management strategies.

Overall, the results confirm that the developed prototype can provide a practical and flexible solution for precision seeding applications involving intercropping, multi-variety sowing, and variable-rate seeding. Future studies will focus on long-term field validation under different soil and climatic conditions, evaluation of prescription-based variable-rate applications, and further optimization of the electronic control and seed metering systems.

Acknowledgments

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