Agronomy Research **23**(1), 393–400, 2025
https://doi.org/10.15159/AR.25.044

Evaluating the efficiency, environmental impact, and operator benefits of GPS guidance and autosteer technologies in agricultural field operations

H. Haapala*, K. Sarvela, J. Kalmari, I. Appelgrén and P. Linna

Jamk University of Applied Sciences, Department of Engineering, Institute of Bioeconomy, Tuumalantie 17, FI43130 Tarvaala, Finland
*Correspondence: hannu.haapala@jamk.fi

Received: February 1st, 2025; Accepted: May 9th, 2025; Published: May 16th, 2025

Abstract. This study evaluated the benefits of GPS guidance and autosteer technologies in agricultural operations through a three-year field experiment conducted at the Smart Bioeconomy Testbed in Central Finland. Adjacent fields were sown either with or without the use of GPS guidance and autosteer, while all other variables were standardized to isolate the impact of the technologies. The movement of the tractor–seeder combination was precisely tracked using RTK GPS with centimetre-level accuracy, and operational parameters were recorded via ISOBUS, supplemented by external measurements of environmental and agronomic factors.
Key findings demonstrated that GPS-guided autosteer operations reduced total work time by 9.7% ($p < 0.01$), primarily due to a 21% ($p < 0.01$) decrease in overlap and unnecessary movement. This operational efficiency translated into a 20% ($p < 0.01$) reduction in fuel consumption and a corresponding decrease in CO_2 emissions per hectare. Moreover, GPS-based automation produced more uniform traffic patterns, mitigating localized soil compaction. Operator well-being also improved, with a 10% ($p < 0.01$) reduction in average heart rate, suggesting reduced physical strain. These benefits were particularly significant in small, irregular fields typical of Finnish agriculture.
In conclusion, GPS guidance and autosteer technologies significantly enhance operational efficiency by reducing fuel use, field time, and emissions. These benefits are particularly pronounced in smaller fields, such as those typical in Finland, where improved manoeuvrability yields greater returns. While the technologies contribute positively to operator well-being, individual responses may vary. Further research is needed to assess long-term impacts, explore integration with advanced technologies such as robotics and AI-driven decision support systems, and address the challenges associated with broader adoption.

Key words: autosteer, environmental impact, GPS guidance, operational efficiency, precision agriculture.

INTRODUCTION

Precision agriculture is undergoing a major transformation through the integration of advanced technologies aimed at optimizing field operations (Haapala, 1995; Griffin et al., 2018; Stafford, 2000; Dayıoğlu & Turker, 2021). Traditionally, its primary goals have been to reduce environmental impact and improve the economic efficiency. In recent years, increasing attention has been given to usability aspects, including ease of use and the need for improved human-machine interfaces (Haapala, 2013; Sebald et al., 2024). The emergence of the Internet of Things (IoT), artificial intelligence (AI), and enhanced data analytics is further expanding the potential for optimization (Balafoutis et al., 2020). Consequently, the term 'Smart Agriculture' is currently preferred over Precision Farming, reflecting a shift from a purely technological focus toward a more integrated approach to agricultural innovation.

Among the precision agriculture technologies, GPS guidance and autosteer systems are increasingly adopted to enhance accuracy, reduce operator workload, and improve overall efficiency (FutureFarming, 2021; Nowak, 2021; Garcia et al., 2023; Sarvela et al., 2024). However, empirical studies assessing their direct impact on operational performance, environmental sustainability, and worker comfort and well-being remain limited (Bongiovanni & Lowenberg-Deboer, 2004; Robertson & Swinton, 2005; Schimmelpfennig, 2016, Papadopoulos et al., 2025). This study addressed this gap by conducting a controlled field experiment over three years in Central Finland.

MATERIALS AND METHODS

The study was conducted over three growing seasons (2022–2024) on adjacent fields at the Smart Bioeconomy Testbed in Saarijärvi, Central Finland (Haapala et al., 2024; Fig. 1).

The experimental setup included two main treatments. In the manual operation (Control), the tractor (Valtra N175D) equipped with a 3 m wide combine drill (Tume Super Nova Combi 3000) was operated manually without GPS guidance or autosteer. In the automated operation (Treatment), the tractor was operated using GPS-based autosteer and automated headland turning (Fig. 2).

To ensure valid comparisons, identical machinery and field conditions were maintained across treatments. Furthermore, all operators underwent thorough training before the experiments commenced.

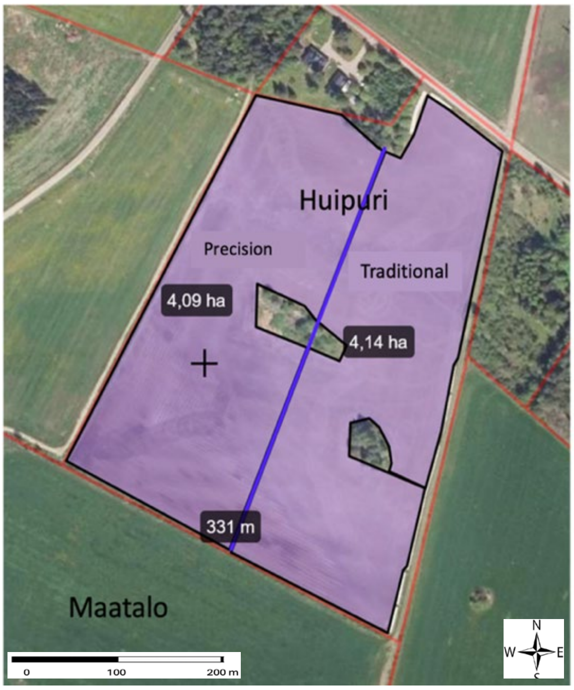

Figure 1. The test fields at the Smart Bioeconomy Testbed in Saarijärvi, Central Finland. The manually operated area is on the right (Traditional), while the automated system is on the left (Precision).

Data collection

Equipment and tracking

Real-Time Kinematic (RTK) GPS was used to enable centimetre-level tracking of tractor movement.

Additionally, ISOBUS logging recorded machine operational data, including the mode of operation, speed, and fuel consumption.

Figure 2. The tractor (Valtra N175D) with autosteer and automated headland turning functionalities.

Environmental and agronomic monitoring

The test fields were managed using precision farming techniques, where the automated area was treated with variable rate control and the manually managed area with constant values. This approach did not affect the treatment itself but ensured the availability of essential background data.

Temperature, humidity, and precipitation were recorded with weather stations. Soil moisture, temperature and nutrient levels were measured with soil sampling, buried soil sensors (SoilScout), and soil scanning (Veris). Soil compaction was measured with a GPS-positioned penetrometer (Eijkelkamp Penetrologger). Frequent (1–2 times a week) drone imaging (eBee fixed-wing drone) with RGB, multispectre and thermal cameras was conducted to measure the crop stand development. Manual measurements of crop development were also done. Crop yield was assessed post-harvest with Farm TRX yield monitor and weighing. These datasets facilitated treatment comparisons and ensured result comparability (Figs. 3–5).

Figure 3. Placement of 20 wireless soil sensors and data repeaters (SoilScout) in the different soil zones of the experimental fields.

Operator stress monitoring

Heart rate and its variability (HRV) was measured in 2024 with a HRV monitor (Firstbeat) as an indicator of stress levels during the seeding work. HRV is the physiological phenomenon of variation in the time interval between consecutive heartbeats in milliseconds, and it is widely used to indicate stress and recovery during work (Draghici & Taylor, 2016).

Figure 4. Soil scanning (Veris) and deep soil sampling (Wintex) of the test fields.

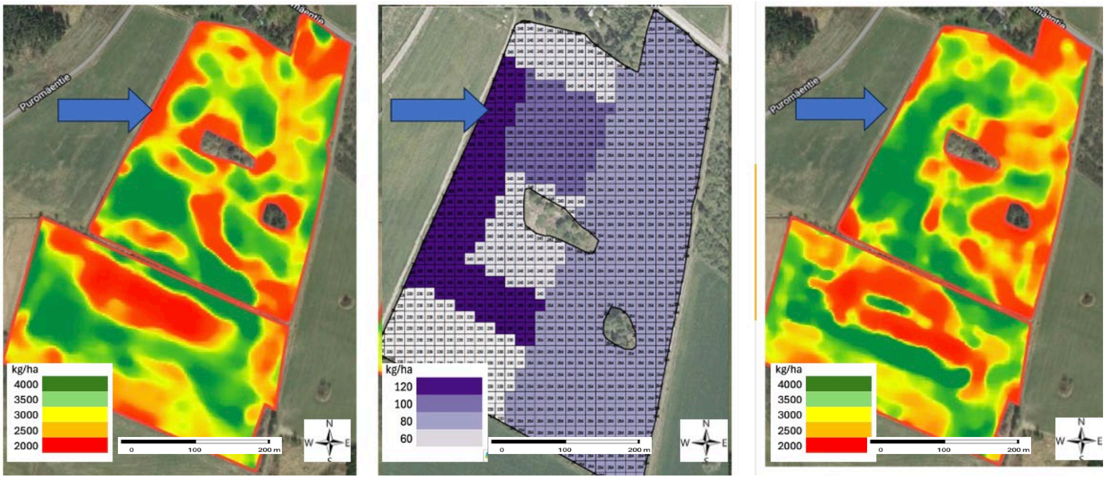

Figure 5. Yield map from 2022, variable rate control of nitrogen in 2023, and grain yield in 2023 in the test fields. The variable rate control increased the uniformity of yield (top left).

HRV was measured continuously during operation and several days before and after the test period to ensure calibration to the test persons normal values. The driver was already experienced with the technologies, thereby minimizing the potential influence of first-time-use novelty on the results.

RESULTS

Before analysis, raw data were filtered to eliminate inconsistencies caused by field obstacles or operational stops (e.g. removing seeding machine malfunctions or picking stones from the field). The data were analysed using a Geographic Information System software (QGIS). Python software was used to manage the data, e.g. the ISOBUS data and FarmTRX data were cleaned before analysis.

The primary finding of the study was the distinct driving patterns between the two treatments (Fig. 6). The manual driving pattern also variated between years.

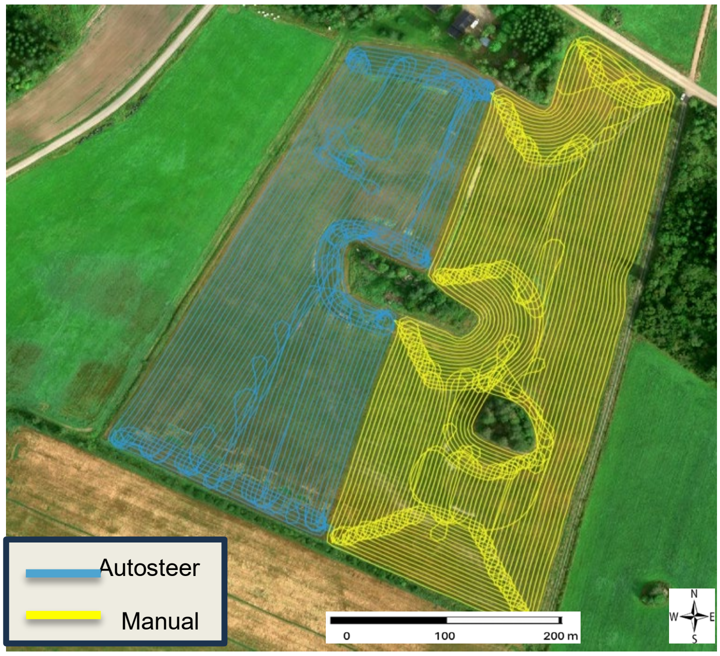

Figure 6. Driving patterns during seeding in 2022 (as visualized in QGIS). Manual operation (right) and autosteer (left).

Operational efficiency

The automated operations (autosteer and automatic headland turns) reduced work time by 9.7% ($p < 0.01$) as compared to manual driving. This was due to the reduced distance driven per area. GPS guidance optimized pathing, decreasing overlap and unnecessary movement by approximately 21% ($p < 0.01$).

Environmental impact

GPS-guided operations resulted in more uniform traffic patterns and less driving distance, reducing the risk of soil compaction. The 20% ($p < 0.01$) lower fuel consumption translated to a corresponding reduction in CO_2 emissions per hectare.

Operator comfort and well-being

Autosteer use led to a 10% ($p < 0.01$) reduction in average heart rate compared to manual operation (Fig. 7).

Figure 7. Heart rate during manual operation (right) vs. autosteer operation (left) during seeding in 2024. The average level was 10% less ($p < 0.01$) when using the autosteer.

HRV differences were also observed, warranting further investigation. Subjective feedback indicated that operators experienced less fatigue and improved focus while using the automated system.

DISCUSSION

The findings regarding improvements in operational efficiency and environmental impact are consistent with those reported in recent studies (Branson, 2011; Antille et al., 2015; Balafoutis, van Evert & Fountas, 2020; Papadopoulos et al., 2025). However, the magnitude of benefits observed in this study was greater than in previous research. For instance, a wide survey conducted in the USA by Bora et al. (2012) reported a 6% reduction in time and a 6.32 % reduction in fuel consumption when guidance systems were employed. Additionally, the farms utilizing autosteering achieved time savings of 5.75% and fuel savings of 5.33%.

The differences observed in comparison to this study suggest that plot size plays a significant role in determining the extent of the benefits achieved. This is in accordance with previous findings (Holpp et al., 2013; Kvíz & Kroulík, 2017). In Finnish conditions, where agricultural plots tend to be smaller, the use of guidance systems and autosteering appears to offer even greater advantages. Smaller plots typically necessitate the use of narrower machinery, which in turn increases the frequency of turning and the need for precise navigation – operational conditions under which advanced technologies can effectively mitigate inefficiencies and reduce fuel consumption.

In terms of operator well-being and comfort, the observed reduction in heart rate and the highly positive user feedback on the use of autosteer were consistent with previous research (Holpp et al., 2013; Kvíz & Kroulík, 2017). Users also expressed strong approval of the increased implementation of robotics in agriculture. (D'Antoni et al., 2012; Papadopoulos et al., 2025)

However, the literature also emphasizes a significant number of potential challenges associated with the growing adoption of robotics in agriculture including e.g. the inadequate mental activation during automation (Bashiri & Mann, 2015; Thompson et al., 2019; Balafoutis et al., 2020).

CONCLUSIONS

This study demonstrated that GPS guidance and autosteer technology significantly enhance operational efficiency, reducing fuel consumption and field time. Additionally, these technologies offer environmental benefits, such as lower CO_2 emissions and reduced risk of soil compaction.

Plot size significantly affects the benefits of guidance systems and autosteering. In regions such as Finland, where fields are smaller and machinery narrower than in many other areas, these technologies significantly enhance efficiency by reducing fuel consumption and operational inefficiencies, particularly through improved turning and navigation. Moreover, autosteer and automated headland turns tends to improve operator well-being and comfort, minimizing stress and fatigue. However, due to the strong influence of individual driver behaviour, further investigation is warranted.

Future research should investigate the long-term impacts of these technologies and explore their integration with advanced precision agriculture tools, including field robotics and AI-driven decision support systems. Although the operators primarily highlighted the benefits, the challenges associated with using autosteer should also be addressed.

ACKNOWLEDGEMENTS. We extend our gratitude to the project's main funder, the Regional Council of Central Finland, for the EU-supported REACT and JTF funding we received, which was essential for the realization of the project. We also thank the project's co-implementer, the Northern Central Finland Vocational College (POKE), whose fields and personnel facilitated the experiments. Our appreciation also goes to our partners: Valtra Ltd, Mtech Ltd, SoilScout Ltd, MTK Ry, AgcoPower Ltd, Neste Ltd, and the city of Saarijärvi. Their support was crucial to the success of the project.

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