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Semi-Automatic Guidance vs. Manual Guidance in Agriculture: A Comparison of Work Performance in Wheat Sowing

Antonio Scarfone [1], Rodolfo Picchio [2,*], Angelo del Giudice [1], Francesco Latterini [1], Paolo Mattei [1], Enrico Santangelo [1] and Alberto Assirelli [1]

[1] Council for Agricultural Research and Economics, Research Centre for Engineering and Agro-Food Processing, 00015 Monterotondo, Italy; antonio.scarfone@crea.gov.it (A.S.); angelo.delgiudice@crea.gov.it (A.d.G.); francesco.latterini@crea.gov.it (F.L.); paolo.mattei@crea.gov.it (P.M.); enrico.santangelo@crea.gov.it (E.S.); alberto.assirelli@crea.gov.it (A.A.)

[2] Department of Agriculture and Forest Sciences (DAFNE), Tuscia University, 01100 Viterbo, Italy

* Correspondence: r.picchio@unitus.it

Abstract: The use of digital systems in precision agriculture is becoming more and more attractive for farmers at every level. A few years ago, the use of these technologies was limited to large farms, due to the considerable income needed to amortize the large investment required. Although this technology has now become more affordable, there is a lack of scientific data directed to demonstrate how these systems are able to determine quantifiable advantages for farmers. Thus, the transition towards precision agriculture is still very slow. This issue is not just negatively affecting the agriculture economy, but it is also slowing down potential environmental benefits that may result from it. The starting point of precision agriculture can be considered as the introduction of satellite tractor guidance. For instance, with semi-automatic and automatic tractor guidance, farmers can profit from more accuracy and higher machine performance during several farm operations such as plowing, harrowing, sowing, and fertilising. The goal of this study is to compare semi-automatic guidance with manual guidance in wheat sowing, evaluating parameters such as machine performance, seed supply and operational costs of both the configurations.

Keywords: precision agriculture; working times; theoretical field capacity; effective field capacity; RTK-GNSS

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1. Introduction

Today, transformation towards digital agriculture represents the new frontier of agricultural production, and it is recognized as the most valid solution to increasing the quality and sustainability of future food production worldwide [1–3]. Digital agriculture entails the transition from a conventional agriculture concept to a smart farming approach. In conventional agriculture, the agronomic input for soil cultivation, such as the use of fertilizers, herbicides, pesticides, and water, is not totally controlled, resulting in a waste of resources and environmental problems for many years [4,5]. A smart farming approach, by contrast, aims at minimizing the use of resources by intervening only where needed [6]. This approach is also known as Precision Agriculture (PA), in other words, a discipline gathering electronic, computer and mechanical technologies in order to maximize agricultural production in a sustainable and efficient way [7]. The match between mechanical and electronic technologies is considered a key factor for success in many sectors on land and beyond [8]; however, common issues concern how these technologies will be spread and how fast the transition will occur. In order to provide an accurate application of precision farming, it is necessary to make inferences on the basis of collected and processed data, availing experts in the area [9].

In the context of PA, the authors stress that the transition process occurs slowly, mainly as a result of the complexity of technologies, incompatibility of components, time requirements, and lack of profitability [10–13]. As regards the costs, the advanced application of PA is obtained by the combination of satellite driving systems, mounted on tractors and precision agriculture machines, and digital maps or databases that are specifically created [10,14,15]. Basically, these technologies allow particular operations, for instance, the application of products such as fertilizers, herbicides, pesticides and seeds at variable rates, i.e., only where they are needed and in the desired amount. However, the costs to set up an entire machine fleet for several application fields is very high, requiring careful attention to determine their impact on the profitability [16]. In this sense, statistics suggest that large investments, such as those required for a full and efficient PA conversion, are not affordable for the majority of European farmers. In fact, considering the average size of farms in UE-28 (16.1 hectares) [17], it is easy to imagine that the revenues generated by small and medium farms are not enough to justify the high costs for such technology. For this reason, the adoption of PA is not largely diffused, and the application of these solutions is limited to a small number of large farms [18].

The reluctancy of farmers to invest in PA is an additional problem slowing down the transition process [19,20]. Farmers have always relied on personal experience for the management of their cultivation, especially in the field of mechanization, where the use of tractors and other self-propelled machines requires specific human skills [21]. It is therefore clear that the conversion process, from conventional agriculture to PA, should be gradual and driven by economic viability and social acceptance, particularly for small- and medium-size farms without significant means to invest. Despite this, automation in agriculture has reached very high levels [22]; the very first and unavoidable step toward the adoption of PA consists in the installation of assisted or automatic guidance on tractors. In particular, automatic guidance has been the first innovation, introduced as a PA solution, to be considered one of the most important and appreciated options in agriculture nowadays [23]. In recent years, this technology has also become more affordable than it was previously [23–25]. This system is based on Global Navigation Satellite System technology (GNSS) and it can be mounted on most models of existing commercial tractors. It makes it possible to perform precision driving on repeatable trajectories, reducing field overlapping due to human errors and the stress of the operators, simultaneously increasing machine productivity and enhancing the possibility to work at night and in conditions of scarce visibility [26,27].

By means of automatic guidance, all operations are fully automated, including turning at the end of the field. A variant of automatic guidance is semi-automatic guidance, in which the operators perform the tractor turning manually. This last system is much more diffused than fully automatic guidance. However, in both driving systems, the operator can fully re-acquire the control of the tractor through the steering wheel, in order to adjust the trajectories.

The costs to just set-up an existing tractor with automatic and semi-automatic guidance are estimated to range from €2000 to about €40,000, according to the precision level required [28,29]. Indicatively, the costs rise with increasing precision. For instance, the use of a lightbar/GPS (assisted driving) allows for a precision level close to 30 cm to be attained, and the cost for its installation is almost €2000 for the less expensive models; while for RTK-GPS (Real-Time Kinematic) correction, the precision level can reach 2–3 cm, and the cost is about €40,000 [30,31]. In any case, these costs are much lower if compared to a full set of machines and technologies needed, thus becoming more affordable for many farmers.

Many of the advantages related to the simple application of automatic guidance are usually stressed by producers, but a specific field analysis, able to evaluate the cost and the benefits of basic PA application, in comparison to conventional agriculture, is missing. The goal of this paper is to present a comparative field study concerning semi-automatic and manual guidance approaches, throughout the sowing of winter wheat, focusing on both technical and economic aspects. The machine performances, along with the sustainability of the process, have been evaluated to investigate whether the digital system is able to provide advantages in a very common field operation.

2. Materials and Methods

The trial took place in the experimental farm of CREA-IT, located in the municipality of Monterotondo (Rome). The experimental field was a flat homogenous terrain area of 5 hectares. The seeds utilized were *Triticum durum* Desf. Variety Platone, while the sowing system was done by a tractor, New Holland mod. T7.185 (New Holland, PA, USA) standard wheelbase, displacement of 6728 cm^3 and a power of 138 kW), and by a pneumatic sowing machine, Kneverland mod. DL, with a working width of 4 m and 32 operating sowing lines. This tractor model was had a semi-automatic guidance system IntelliSteer, compatible with the correction systems EGNOS and RTK. The IntelliSteer technology includes a NH 372 GNSS receiver, a sensor for the steering angle, a Navigation Controller III and an electro-hydraulic distributor.

In operative conditions, the steering angle sensor transmits the signals referred to the forward direction of the tractor to the navigation controller. The electro-hydraulic distributor converts the signals in hydraulic movement, by acting directly on the power steering of the machine. By associating this technology to the EGNOS correction, it is possible to reach precision levels within a range of ±20 cm, while the correction in Real-Time Kinematic (RTK) allows the precision level to increase up to ±1–2.5 cm. The tractor functions are controlled through an integrated virtual terminal, model IntelliView IV. In this study, considering the precision level needed by the sowing operation, an RTK base station was installed near the field edge, in order to achieve RTK correction. The base station was composed of a geodetic GPS antenna Trimble model Zephyr 3 (Sunnyvale, CA, USA) and a GPS receiver AgGPS RTK Base 450/900 (Sunnyvale, CA, USA), which incorporates the power supply and the RTK radio transmission. The geodetic antenna is formed by a circular plate of 34.3 cm in diameter and 7.9 cm in height; this design was searched to optimize the functioning and to eliminate multipath (the major source of GPS errors); the Zephyr 3 has GNSS support, including GPS Modernization signals (L1,L2,L5), GLONASS (L1,L2,L3), BeiDou (B1,B2,B3), Galileo (E1,E5a,E5b,E6), QZSS (L1,L2,L5, LEX), IRNSS (L5). Separately from the antenna, the receiver has a compact prismatic profile (LWH −24 cm × 12 cm × 5 cm) and a weight of 1.65 kg including the RTK radio transmission; it is separated from the geodetic antenna to allow for positioning in a protected environment if needed. The power supply consists of 7.4 V/7800 mA-hr battery that at full charge, can reach a life of up to 10 h. A display interface is present for menu setting and status checking. The range of action of the receiver is 12.8 km. The communication specifications are as follows: channel spacing (450 MHz)—12.5 KHz or 25 KHz radio spectrum available; for a 450 MHz transmitter, the radio power output is 0.5–2.0 W; for a 900 MHz transmitter, the radio power output is 1 W.a (Figure 1).

Figure 1. (**a**) RTK Base Station; (**b**) Tractor with technology IntelliSteer equipped with a pneumatic seeder.

2.1. Experimental Design

The experimental design was conceived with a view to compare two treatments, i.e., semi-automatic guidance (SG) and manual guidance (MG), replicated three times, where one replicate was represented by 10 passes of the tractor in the field (10 rows) covering a surface of 0.8 ha. Such surface per replicate was assessed by measuring the working width of the machines and the length of the field. In total, sixty tractor passes (60 rows) were performed, 30 in SG (three replicates) and 30 in MG (three replicates). For practical reasons, and considering the homogeneity of the field, the replicates of SG and MG were performed in sequence rather than in a randomized scheme.

2.2. Machine Setting

Before sowing, machine adjustments were made on both tractor and seeder, to meet the desired results in terms of machine alignment (tractor) and seed quantity distribution (seeder). In SG, and especially in sowing, the accurate setting of certain parameters on the tractor is very important in order to avoid defects, such as generating field overlapping or empty strips. In this regard, the machine working width and the machine decentralization, in respect to the central axis of the tractor, were the main parameters considered. These were evaluated through a mock sowing, performed the day before the test in another field.

During the field tests, upon the setting of the RTK base station, semi-automatic guidance was activated, recording a linear trajectory in the field through the virtual terminal IntelliView IV, starting at point A and concluding at point B. The software in the virtual terminal automatically adjusted the trajectory, creating parallel-linear lines, even if the passage A–B was not precisely linear. The lines created represented the passes that the tractor automatically followed in SG. For the seeder regulation, mechanical adjustments were applied to ensure a seed drop included in a range between 210 and 230 kg ha^{-1}.

2.3. Evaluation of the Seed Utilized

To compare the supply of seed utilized in SG and MG, the exact amount of seed distributed for each replicate was quantified. Before starting each replicate, a measured weight of seeds (200 kg) was loaded into the seeder tank and utilized to carry out the operation. At the end of each replicate, the residual seeds in the seeder tank were unloaded into a plastic basket and weighed using a dynamometer Kern mod. CH 50K100 (d = 0.1). The exact amount of seed for each replicate was therefore determined by the difference. The seeder tank was always loaded with 200 kg seeds, in order to have enough supply in any case, considering each replicate dimension (0.8 ha) and the seeder distribution settings (210–230 kg ha^{-1}). At the end of each replicate, different pickets were placed along the boundaries to mark and successively quantify the exact area sown. Finally, the exact amount of seeds used, and the exact sown area were identified for each replicate.

2.4. Machine Performance

To assess the work capacity and the productivity of the machine in the two driving modalities, the operative performance of the tractor was assessed for each replicate, adopting the standard protocol proposed by Reith et al. [32]. This approach is based on the analysis of working time count, and it is used by researchers to test the performance of different types of agricultural machines [33]. In detail, working times were subdivided as the following: effective operating time, accessory time, time for turning and time for adjustments. Elaboration of working times allowed to estimate the theoretical field capacity (TFC, ha h^{-1}) and the effective field capacity (EFC, ha h^{-1})

- TFC: Working speed x working width;
- EFC: Sown surface/overall working times

The operator performing the test was an agricultural specialised worker, with several years of experience of driving tractors, even in a semi-automatic guidance modality.

Fuel consumption was determined according to the methodology proposed by Grisso et al. [34], which is obtained by the product of specific volumetric fuel consumption of a given tractor (liter kWh^{-1}) for the tractor engine power (PTO equivalent) utilized for sowing (kW).

2.5. Work Quality

Despite seed consumption and machine operativity, another important parameter to be evaluated was the work quality achieved with both systems, by identifying unsown areas left in the field. In fact, it is possible that during the test in both SG and MG, eventual signal problems or distractions of the operator could determine some field overlapping, or the exclusion of some areas. The quantification of these areas was performed 45 days after sowing, when seedling clearly emerged, making unsown areas more evident (Figure 2).

Figure 2. (**a**) Field sown in semi-automatic guidance (SG); (**b**) field sown with in manual guidance (MG).

The impossibility to fly in the aerial space with drones, due to restrictions present in the area (red zone due to presence of airports and heliport), and the scarce resolution of the available satellite images, made it necessary to perform a manual inspection. The areas in both SG and MG were evaluated in each replicate, according to the location, by a metric tape and a laser distance meter (Figure 3).

Figure 3. Unsown areas identified in the field, three different zones are reported as an example (**a**–**c**).

2.6. Economic Analysis

The economic evaluation of SG and MG was based on the purchase costs of machine and equipment (financial costs), fixed costs and variable costs, following the methodology proposed by previous studies and according to the market value of agricultural machinery [35]. In particular, the total yearly fixed costs of the machineries, that were assessed starting from the machine purchase price, were divided for the machineries' annual usage (in hours) to get the hourly fixed cost. Hourly variable costs (maintenance, fuel, lubricant and manpower) were calculated using the abovementioned methodologies. In this way, it was possible to obtain the total hourly costs of the sowing system. To obtain costs per surface unit, the calculated overall hourly costs were multiplied for the time needed to sow one hectare.

The main parameters considered for the evaluation are given in Table 1.

Another important parameter, affecting the economic evaluation, is the price of the certified durum wheat seed t^{-1}. The reference value was identified through a market analysis and it corresponded to €580 t^{-1} (€0.58 kg^{-1}) [36].

Table 1. Scheme of the parameters considered for the economic analysis.

			Seeder Kneverland Mod. DL	Tractor NH—T7 Autocommand with Satellite Guidance and RTK Base Station	Tractor NH—T7 Autocommand without Satellite Guidance
Financial costs	Investment	€	15,200	130,000	92,000
	Service life	year	10	10	10
	Service life	h	4800	10,000	10,000
	inflation		1.12	1.12	1.12
	Resale	%	17.7	29.5	29.5
	Resale	€	2688.0	43,149.6	30,536.6
	Depreciation	€	12,512.0	86,850.4	61,463.4
	Annual usage	h/year	100	1000	1000
	Interest rate	%	3.0	3.0	3.0
Fixed costs	Ownership costs	€/year	1251.2	6685	6146.3
	Interests	€/year	268.3	2597.2	1838.0
	Machine shelter	m^2	12.0	12.72	12.72
	Value of the shelter	€/m^2	100.0	100.0	100.0
	Value of the shelter	€/year	24.00	25.44	25.44
	Insurance	€/year	38.0	325.0	230.0
	miscellaneous expenses	€/year	62	350	255
Variable costs	Repair factor	%	40	80	80
	Repairs and maintenance	€/h	0.26	10.4	7.36
	Fuel unit cost	€/l	0.57	0.574	0.57
	Fuel consumption	l/h		6.18	6.18
	Fuel cost	€/h	0.00	3.55	3.55
	Lubricant unit cost	€/l	0.00	3.03	3.03
	Lubricant consumption	l/h	0.00	0.10	0.10
	Lubricant cost	€/h	0.00	0.31	0.31
	Number of workers	n°		1	1
	Salary for worker	€/h		11.5	11.5

2.7. Statistical Analysis

During our tests on the SG technology, the accuracy as the fraction of predictions our model got right (accuracy = Number of correct predictions/Total number of predictions) was assessed. Data were analyzed using the PAST software [37], version 3.22 (2018, Øyvind Hammer, University of Oslo, Norway). Data were checked for normality by Shapiro–Wilk test, and for the homogeneity of variance through the Levene test. The differences between SG and MG concerning machine performance parameters (field efficiency, effective field capacity, effective field speed, turning time), fuel consumption and seeds used per unit of surface, were analyzed by Analysis of variance (ANOVA). Means were separated according to the Tukey honestly significant difference (HSD) test. The same software was also used to run a principal component analysis (PCA) on SG and MG, on the basis of the following variables: seeds used per unit of surface, turning time, effective field capacity, effective field speed, field efficiency, and fuel consumption.

3. Results

For SG, the findings show a positioning accuracy 1 cm and a horizontal accuracy near to 95%. The mock sowing, performed during the pre-check analysis, displayed the absence of machine decentralisation in respect to the central axis of the tractor, but revealed an effective working width of 3.95 m—approximately 5 cm less than the working width declared by the producer. Unsown areas were in total 0.029 ha, identified only in the replicates of MG, as shown in Figure 4.

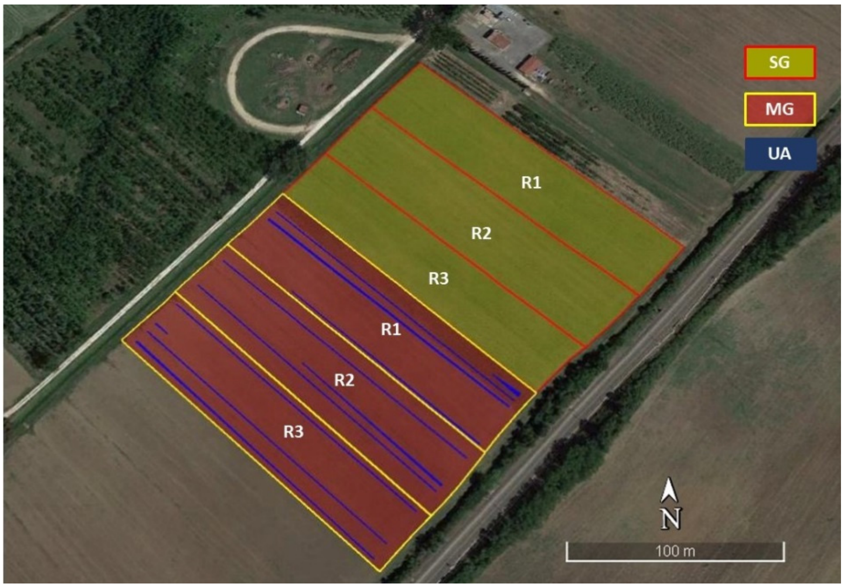

Figure 4. Unsown areas (UA) identified in the treatment MG; not present in treatment SG.

In Table 2, a summary is shown reporting the measured surface of each replicate (ha), the unsown areas (ha), the quantity of seed effectively used in each replicate (kg) and the amount of seed effectively used per unit of surface in the specific replicate (kg ha^{-1}).

Table 2. Surface and seed utilised in each replicate.

		Semi-Automatic Guidance					**Manual Guidance**				
Replicate	Unit	R1	R2	R3	Tot.	Mean ± St.dev.	R1	R2	R3	Tot.	Mean ± St.dev.
Theoretical Worked surface	(ha)	0.805	0.78	0.65	2.235		0.76	0.73	0.67	2.1653	
Unsown areas	(ha)	none	none	none	none		0.009	0.012	0.008	0.029	
Effective worked surface	(ha)	0.805	0.78	0.65	2.235		0.751	0.718	0.662	2.1363	
Seed used	(kg)	184.1	177.2	147.7	509		175.5	168.5	154.8	498.8	
Seeds used per unit of surface	(kg ha^{-1})	228.7	227.2	227.2		227.7 ± 0.7	233.7	234.7	233.8		234.1 ± 0.43

Both PCA and analysis of variance displayed the presence of significant differences among the two systems, considering the seeds used per unit of surface, indicating that SG effectively allowed the amount of seeds utilized to be reduced to 6.4 kg ha^{-1} on average (Figure 5 and Table 2). Therefore, the quantity of seeds used in SG was 2.73% lower than MG, resulting in a net saving of €3.71 ha^{-1} (according to the current market price of wheat seeds).

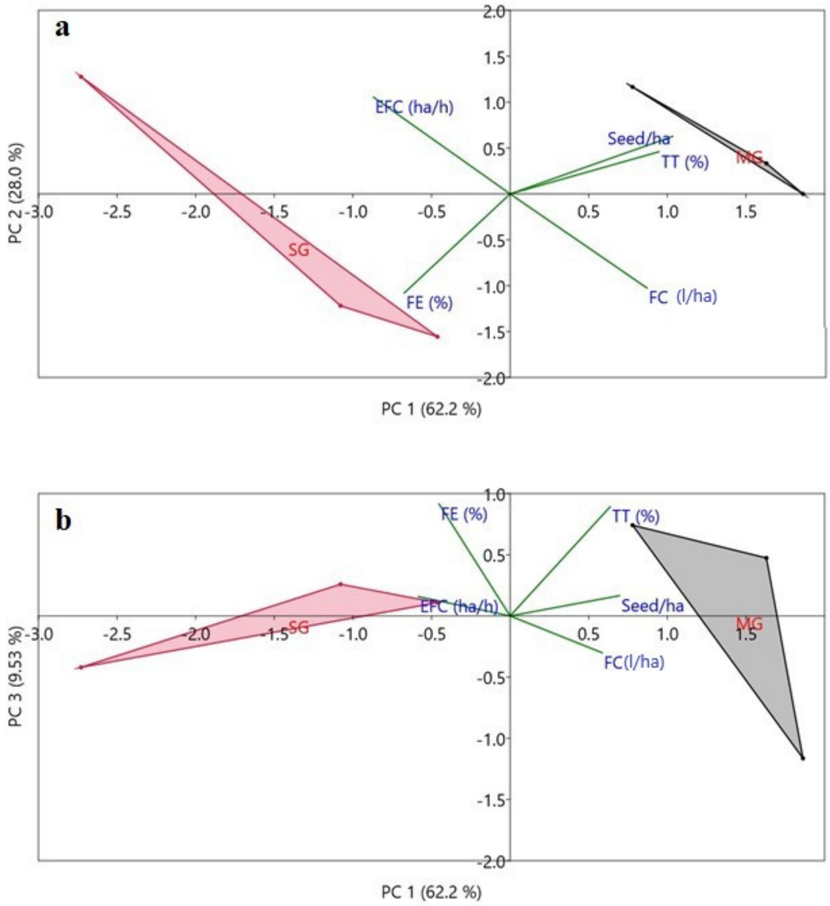

Figure 5. Principal Component Analysis performed considering seeds used per unit of surface (seed/ha), field efficiency (FE), effective field capacity (EFC), effective field speed (EFS), turning times (TT) and fuel consumption (FC). The plots represent the combination of PC1 with PC2 (**a**) and PC3 (**b**).

Regarding the tractor performance, in Table 3, the collected data concerning SG and MG are displayed, respectively.

Both PCA and ANOVA display significant differences among treatments concerning Field Efficiency and Turning Time; however, no differences were identified in the effective field speed, effective field capacity and fuel consumption. The graph of the PCA is shown in Figure 5, while the table of the ANOVA is reported below (Table 4).

The first three components of PCAs explained almost the whole variance (99.73%). As shown in Figure 5, the principal components were PC1 (62.2%) and PC2 (28.0%), while the third component described the remaining 9.53% (Figure 5b). Further detailed information about the factor loading is given in Appendix A (Table A1). The PCA plots emphasized the clear separation between MG and SG groups. In both cases (Figure 5a,b), the areas of MG and SG were placed in opposite quadrants, with respect to the PC1 axis.

Seed used, turning time and fuel consumption were more influenced by the MG, while the field efficiency and the effective field capacity were more affected by SG. Such observations were confirmed by data reported in Table 4. On the one hand, the MG showed higher seed consumption (234.1 kg ha^{-1} vs. 227.7 kg ha^{-1}) and turning time, with a statistically significant difference. The fuel consumption was, likewise, higher for

MG than SG (2.86 l ha^{-1} vs. 2.68 l ha^{-1}), although such difference did not reach any statistical significance. On the other hand, the field efficiency was significantly higher for SG (65.2% vs. 60.6%) and the effective field capacity was not significant, but slightly higher than MG. Interestingly, by analysing the position of vectors in Figure 5a, it emerged that the FC is inversely related to EFC, and the FE is inversely related to the seed consumption and the TT. Consistent with the results, it is clear that fuel saving will lead to an increase in the EFC, while due to the reduction of the time for turning, and the lower seed distributed over the equal surface area, the FE is expected to increase (Table 4).

Table 3. Tractor performance semi-automatic guidance (SG).

		Tractor with SG				**Tractor with MG**			
Working times	Unit	R1	R2	R3	Mean ± st.dev	R1	R2	R3	Mean ± st.dev
Effective operating time	%	66.48	66.39	62.81	65.22 ± 1.71	58.50	61.77	61.68	60.65 ± 1.52
Accessory time	%	33.52	33.61	37.19	34.77 ± 1.71	41.50	38.23	38.32	39.35 ± 1.52
Time for turning	%	33.52	33.61	31.50	32.8 ± 0.97	35.47	38.23	38.32	37.34 ± 1.32
Time for adjustments	%	-	-	5.69		6.03	-	-	
Machine performance	Unit	R1	R2	R3	Mean ± st.dev	R1	R2	R3	Mean ± st.dev
Field efficiency	%	66.48	66.39	62.81	65.23 ± 1.71	58.50	61.77	61.68	60.65 ± 1.52
Theoretical field speed	m s^{-1}	2.21	2.31	2.92	2.48 ± 0.31	2.43	2.43	2.62	2.49 ± 0.09
Effective field speed	m s^{-1}	1.47	1.54	1.83	1.61 ± 0.16	1.42	1.50	1.62	1.51 ± 0.08
Theoretical field capacity	ha h^{-1}	3.17	3.32	4.19	3.56 ± 0.45	3.47	3.47	3.75	3.56 ± 0.13
Effective field capacity	ha h^{-1}	2.11	2.20	2.63	2.31 ± 0.23	2.03	2.14	2.31	2.16 ± 0.12
Fuel consumption	l ha^{-1}	2.91	2.79	2.34	2.68 ± 0.24	3.03	2.88	2.66	2.86 ± 0.15

Table 4. Analysis of variance considering seeds used per unit of surface (seed/ha), field efficiency (FE), effective field capacity (EFC), effective field speed (EFS), turning times (TT) and fuel consumption (FC). Significant difference at $p \leq 0.05$ (*), and $p \leq 0.001$ (***), or not significant (ns).

	MG	**SG**	**F**	**p**
Seed (kg ha^{-1})	234.1	227.7	115.4	***
FE (%)	60.6	65.2	8.03	*
EFC (ha h^{-1})	2.16	2.31	0.73	ns
EFS (m s^{-1})	1.51	1.61	0.64	ns
TT (%)	37.3	32.9	14.78	*
FC (l ha^{-1})	2.86	2.68	0.75	ns

The economic assessment concerning machine usage displayed that the cost per unit of surface (ha) was 0.37% lower in SG, with a net saving of 0.08 € ha^{-1}. The results related to the economic analysis are displayed in Table 5.

Table 5. Table of the cost considering semi-automatic guidance and manual guidance scenarios.

		Seeder (SG Scenario)	**Tractor (SG Scenario)**	**Total**	**Seeder (MG Scenario)**	**Tractor (MG Scenario)**	**Total**
Annual Cost	€ $year^{-1}$	1274.5	37,392	38,666.4	1607.9	30,959.1	32,567
Hourly cost	€ h^{-1}	12.7	37.4	50.1	16.1	31	47
Costs per unit of surface	€ ha^{-1}	5.5	16.2	21.7	7.4	14.3	21.78

Overall, also considering the seeds used, the SG system allowed a reduction of the sowing cost of 2.4%, corresponding to a net saving of €3.79 ha^{-1}. In Figure 6, a diagram of the final economic assessment results is reported.

The largest part of the sowing costs is related to the seed costs, representing approximately 85% of the overall amount.

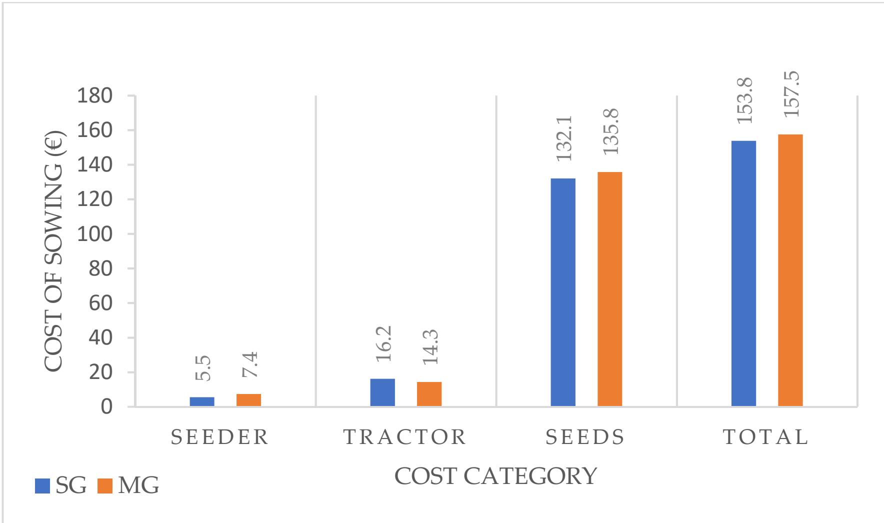

Figure 6. Sum of costs for sowing per hectare in semi-automatic guidance (SG) and manual guidance (MG).

4. Discussion

During our test, the devices used in SG showed a positioning accuracy of up to one centimeter, even lower than that declared by the manufacturer (about 2.5 cm). This is thanks to the process for achieving positioning accuracy up to one centimeter in GNSS that involves the RTK algorithm [25]. Our findings referred to horizontal accuracy (95%) were similar to those showed by Catania et al. [25].

The results display a significant difference among the quantity of seeds distributed in SG and MG, with small savings identified in SG (6.4 kg ha^{-1}). This difference can be related to the satellite system, which made it possible to optimise the tractor passages; therefore, reducing eventual mistakes by the operator. Similar studies, evaluating defects (gaps and overlaps) that occurred during sowing in automatic and manual guidance, are in line with the results of the present research, displaying a higher efficiency of automatic guidance in comparison to the manual guidance, with errors (gaps + overlaps) of 2.5% vs. 5% [38].

The tractor performances were significantly different between SG and MG only with respect to field efficiency and turning times, even if the SG configuration determined an Effective Field Capacity of 0.15 ha h^{-1} higher than MG. Considering a whole working day of 8 h, this difference in productivity can increase the workable surface of 1.2 ha per day. It is possible to link this last difference to the turning times, which were about 5% lower in SG. A reliable explanation lies in the fact that, in conventional sowing, the operator needs to use a row-marker device, later performing multiple maneuvers to align with the previous row, while in SG, the alignment is automatic and very precise. In this way, the operator is rapidly able to start the new row without wasting time. A study conducted in the US confirmed that Automatic Guidance Systems (AGS) applied to an existing farm make it achievable to optimise the time count of field operations, reducing yield penalties, likewise giving the opportunity to expand the farm size by just using the existing equipment set [39]. On the other hand, for contractors (not farm owners), the extra workable surface per day may allow them to optimize the working season, increasing the number of costumers and the potential revenues.

The fuel consumption per ha was 6.3% lower in SG (0.18 L ha^{-1}) than MG, but the difference was not significant. This is probably due to the low surface considered in this study. However, studies focused on energy savings, obtained through optimisation of the in-field route with GNSS, provided similar results, with a reduced fuel energy consumption of up to 8% [40].

The economic evaluation of machines displayed very similar cost per unit of surface, regardless of the driving system used (SG €21.7 ha^{-1} vs. €21.78 ha^{-1}). In the case of SG, the higher tractor costs were due to higher purchase prices of such technology, but they were balanced by the lower cost of the seeder, due to the higher productivity of the machine in the SG configuration. Regarding seeds, considering the average cost of the certified seeds as €0.58 kg^{-1}, the savings obtained were €3.71 ha^{-1}. Similar studies evaluated that cost savings related to automatic guidance, compared to manual guidance, were equal to €8 ha^{-1}.

However, the study did not specify the seed species, and considered all products supplied per unit area (fertilizer, treatment, etc.) without specifying each product cost [38]. As in this study, the machines used were not ISOBUS, but machines already available at the farm site. It is very likely that the use of an ISOBUS seeder would have guaranteed higher results in terms of seed saving, but at the same time, an increase in operating costs related to the higher cost of such technology. Other studies performed in the UK estimated that in a farm of 500 ha, the economic advantage of using a system for automatic guidance in the winter wheat cultivation would be equal €2.2 ha^{-1} [30]. In comparison with our study, the economic advantages in the UK were much smaller, given that the value is referred to all cultivation phases. However, it must be stressed that the study was performed 11 years ago, thus the cost of the technology than compared to that at present has significantly changed. It could be interesting in the near future to carry out studies in order to fully cover an entire cultivation cycle and obtain a more complete economic view.

5. Conclusions

The present work compared the performance of the semi-automatic tractor guidance (SG) with the performance proper of a conventional driving configuration (manual guidance—MG). The parameters taken into account were the seed distribution per unit of surface and the tractor performance. An economic analysis was also performed to quantify the eventual differences in terms of system profitability. The study pointed out that digital technology decreased the operating time, giving the farmers the possibility to sow 1.2 additional ha per day, and reducing the sowing cost by 2.4%, corresponding to net savings of €3.79 ha^{-1}. Fuel consumption in SG was lower than in MG, but differences were not significant for the surface and fuel quantity considered. In conclusion, the satellite guidance made it possible to work with more accuracy, removing human defects completely and reducing the sowing cost. The results of this study provide clear indicators for the achievement of a higher level of sustainability, taking advantage of electronics as a support in tractor guidance.

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Appendix A

Table A1. Loadings.

	PC 1	PC 2	PC 3	PC 4	PC 5
Seed ha^{-1}	0.521	0.3160	0.1243	0.7661	−0.1609
FE (%)	−0.3400	−0.5444	0.6868	0.3411	−0.0152
EFC (ha/h)	−0.4382	0.5313	0.1185	0.2038	0.6856
TT (%)	0.4772	0.2315	0.6693	−0.4959	0.1573
FC (L/ha)	0.4393	−0.5175	−0.2255	0.09635	0.6921

References

1. Balafoutis, A.; Beck, B.; Fountas, S.; Vangeyte, J.; Van der Wal, T.; Soto, I.; Gómez-Barbero, M.; Barnes, A.; Eory, V. Precision agriculture technologies positively contributing to GHG emissions mitigation, farm productivity and economics. *Sustainability* **2017**, *9*, 1339. [CrossRef]
2. Kosior, K. Digital transformation in the agri-food sector–opportunities and challenges. *Rocz* **2018**, *1230*, 98–104. [CrossRef]
3. Pérez, S.S.; López, J.M.G.; Jimenez Betancourt, R.O.; Villalvazo Laureano, E.; Solís, J.E.M.; Sánchez Cervantes, M.G.; Ochoa Guzmán, V.J. A Low-Cost Platform for Modeling and Controlling the Yaw Dynamics of an Agricultural Tractor to Gain Autonomy. *Electronics* **2020**, *9*, 1826. [CrossRef]
4. Zarco-Tejada, P.J.; Hubbard, N.; Loudjani, P. Precision Agriculture: An Opportunity for EU Farmers—Potential Support with the CAP 2014–2020. 2014. Available online: https://www.europarl.europa.eu/RegData/etudes/note/join/2014/529049/IPOL-AGRI_NT%282014%29529049_EN (accessed on 14 March 2014).
5. Le Campion, A.; Oury, F.-X.; Heumez, E.; Rolland, B. Conventional versus organic farming systems: Dissecting comparisons to improve cereal organic breeding strategies. *Org. Agric.* **2020**, *10*, 63–74. [CrossRef]
6. Khan, A.; Ilyas, T.; Umraiz, M.; Mannan, Z.I.; Kim, H. Ced-net: Crops and weeds segmentation for smart farming using a small cascaded encoder-decoder architecture. *Electronics* **2020**, *9*, 1602. [CrossRef]
7. Zhang, N.; Wang, M.; Wang, N. Precision agriculture—A worldwide overview. *Comput. Electron. Agric.* **2002**, *36*, 113–132. [CrossRef]
8. Karimi, H.R. *Offshore Mechatronics Systems Engineering*; Group, T.F., Ed.; CRC Press: Boca Raton, FL, USA, 2018; ISBN 1351733923.
9. Chen, J.-W.; Lin, W.-J.; Cheng, H.-J.; Hung, C.-L.; Lin, C.-Y.; Chen, S.-P. A Smartphone-Based Application for Scale Pest Detection Using Multiple-Object Detection Methods. *Electronics* **2021**, *10*, 372. [CrossRef]
10. Khanna, M.; Epouhe, O.F.; Hornbaker, R. Site-specific crop management: Adoption patterns and incentives. *Appl. Econ. Perspect. Policy* **1999**, *21*, 455–472. [CrossRef]
11. Griffin, T.W.; Lambert, D.M.; Lowenberg-DeBoer, J.M. Testing appropriate on-farm trial designs and statistical methods for precision farming: A simulation approach. In Proceedings of the 7th International Conference on Precision Agriculture and Other Precision Resources Management, Minneapolis, MN, USA, 25–28 July 2004; pp. 1733–1748.
12. Reichardt, M.; Jürgens, C. Adoption and future perspective of precision farming in Germany: Results of several surveys among different agricultural target groups. *Precis. Agric.* **2009**, *10*, 73–94. [CrossRef]
13. Robertson, M.J.; Llewellyn, R.S.; Mandel, R.; Lawes, R.; Bramley, R.G.V.; Swift, L.; Metz, N.; O'Callaghan, C. Adoption of variable rate fertiliser application in the Australian grains industry: Status, issues and prospects. *Precis. Agric.* **2012**, *13*, 181–199. [CrossRef]
14. Picchio, R.; Latterini, F.; Mederski, P.S.; Venanzi, R.; Karaszewski, Z.; Bembenek, M.; Croce, M. Comparing Accuracy of Three Methods Based on the GIS Environment for Determining Winching Areas. *Electronics* **2019**, *8*, 53. [CrossRef]
15. Picchio, R.; Proto, A.R.; Civitarese, V.; Di Marzio, N.; Latterini, F. Recent Contributions of Some Fields of the Electronics in Development of Forest Operations Technologies. *Electronics* **2019**, *8*, 1465. [CrossRef]
16. Shockley, J.; Dillon, C.R.; Stombaugh, T.; Shearer, S. Whole farm analysis of automatic section control for agricultural machinery. *Precis. Agric.* **2012**, *13*, 411–420. [CrossRef]
17. EUROSTAT. Agriculture, Forestry and Fishery Statistics. Publications Office of the European Union. 2016. Available online: https://ec.europa.eu/eurostat/documents/3217494/7777899/KS-FK-16-001-EN-N.pdf/cae3c56f-53e2-404a-9e9e-fb5f57ab49e3 (accessed on 20 November 2020).
18. Lowenberg-DeBoer, J.; Erickson, B. Setting the record straight on precision agriculture adoption. *Agron. J.* **2019**, *111*, 1552–1569. [CrossRef]
19. Prasetyo, Y.; Apriliyadi, E.; Hidajat, E.; Novianti, F. Resistance to innovation: Case of appropriate technology implementation in rural agriculture communities. *Available SSRN 2101656* **2009**. [CrossRef]
20. Griepentrog, H.W. Eine neue Erfolgsformel? Smart Farming soll die nächste Generation von Precision Farming warden. *DLG-Mitteilungen* **2011**, *126*, 12–16.
21. Kharel, T.P.; Ashworth, A.J.; Shew, A.; Popp, M.P.; Owens, P.R. Tractor guidance improves production efficiency by reducing overlaps and gaps. *Agric. Environ. Lett.* **2020**, *5*, e20012. [CrossRef]
22. Kirtan, J.; Aalap, D.; Poojan, P.; Manan, S. A comprehensive review on automation in agriculture using artificial intelligence. *Artif. Int. Agric.* **2019**, *2*, 1–12. [CrossRef]
23. Keicher, R.; Seufert, H. Automatic guidance for agricultural vehicles in Europe. *Comput. Electron. Agric.* **2000**, *25*, 169–194. [CrossRef]
24. Alonso-Garcia, S.; Gil, J.G.; Arribas, J.I. Evaluation of the use of low-cost GPS receivers in the autonomous guidance of agricultural tractors. *Spanish J. Agric. Res.* **2011**, 377–388. [CrossRef]
25. Catania, P.; Comparetti, A.; Febo, P.; Morello, G.; Orlando, S.; Roma, E.; Vallone, M. Positioning accuracy comparison of GNSS receivers used for mapping and guidance of agricultural machines. *Agronomy* **2020**, *10*, 924. [CrossRef]
26. Romano, E.; Bisaglia, C.; Calcante, A.; Oberti, R.; Zani, A.; Vinnikov, D.; Marconi, A.; Vitale, E.; Bracci, M.; Rapisarda, V. Assessment of comfort variation among different types of driving agricultural tractors: Traditional, satellite-assisted and semi-automatic. *Int. J. Environ. Res. Public Health* **2020**, *17*, 8836. [CrossRef]
27. Karimi, D.; Henry, J.; Mann, D.D. Effect of using GPS autosteer guidance systems on the eye-glance behavior and posture of tractor operators. *J. Agric. Saf. Health* **2012**, *18*, 309–318. [CrossRef]
28. Heege, H.J. *Precision in Crop Farming: Site Specific Concepts and Sensing Methods: Applications and Results*; Springer Science & Business Media: Dordrecht, The Netherlands, 2013; ISBN 9400767609.

29. Ortiz, B.V.; Balkcom, K.B.; Duzy, L.; Van Santen, E.; Hartzog, D.L. Evaluation of agronomic and economic benefits of using RTK-GPS-based auto-steer guidance systems for peanut digging operations. *Precis. Agric.* **2013**, *14*, 357–375. [CrossRef]
30. Knight, S.; Miller, P.; Orson, J. An up-to-date cost/benefit analysis of precision farming techniques to guide growers of cereals and oilseeds. *HGCA Res. Rev.* **2009**, *71*, 115.
31. Stempfhuber, W.; Buchholz, M. A precise, low-cost RTK GNSS system for UAV applications. *Proc. Unmanned Aer. Veh. Geomatics ISPRS* **2011**, *XXXVIII-1*, 289–293. [CrossRef]
32. Reith, S.; Frisch, J.; Winkler, B. Revision of the working time classification to optimize work processes in modern agriculture. *Chem. Eng. Trans.* **2017**, *58*, 121–126. [CrossRef]
33. Suardi, A.; Latterini, F.; Alfano, V.; Palmieri, N.; Bergonzoli, S.; Karampinis, E.; Kougioumtzis, M.A.; Grammelis, P.; Pari, L. Machine Performance and Hog Fuel Quality Evaluation in Olive Tree Pruning Harvesting Conducted Using a Towed Shredder on Flat and Hilly Fields. *Energies* **2020**, *13*, 1713. [CrossRef]
34. Grisso, R.D.; Kocher, M.F.; Vaughan, D.H. Predicting tractor fuel consumption. *Appl. Eng. Agric.* **2004**, *20*, 553. [CrossRef]
35. Stefanoni, W.; Latterini, F.; Ruiz, J.P.; Bergonzoli, S.; Palmieri, N.; Pari, L. Assessing the Camelina (Camelina sativa (L.) Crantz) Seed Harvesting Using a Combine Harvester: A Case-Study on the Assessment of Work Performance and Seed Loss. *Sustainability* **2021**, *13*, 195. [CrossRef]
36. Assosementi – Associazione Italiana Sementi. 2020. Available online: http://www.sementi.it/seme-certificato-cereali (accessed on 20 November 2020).
37. Hammer, Ø.; Harper, D.A.T.; Ryan, P.D. Paleontological statistics software package for education and data analysis. *Paleontologia Electronica* **2001**, *4*, 1–9.
38. Radicioni, F.; Stoppini, A.; Brigante, R.; Brozzi, A.; Tosi, G. GNSS Network RTK for Automatic Guidance in Agriculture: Testing and Performance Evaluation. In Proceedings of the Computational Science and Its Applications (ICCSA 2020), Cagliari, Italy, 1–4 July 2020; pp. 19–35.
39. Griffin, T.; Lambert, D.; Lowenberg-DeBoer, J. Economics of lightbar and auto-guidance GPS navigation technologies. *Precis. Agric.* **2005**, *5*, 581–587.
40. Rodias, E.; Berruto, R.; Busato, P.; Bochtis, D.; Sørensen, C.G.; Zhou, K. Energy savings from optimised in-field route planning for agricultural machinery. *Sustainability* **2017**, *9*, 1956. [CrossRef]