EFFECT OF SOWING SPEED AND WIDTH ON SPACING UNIFORMITY OF PRECISION SEED DRILLS
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EFFETTO DELLA VELOCITÀ DI SEMINA SULL'UNIFORMITÀ DI DEPOSIZIONE DEL SEME DI SEMINATRICI PER LA SEMINA DI MAIS E BARBABIETOLA

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ABSTRACT
The precision seed drills significantly improve the competitiveness of farms, in terms of sowing quality and yield. This paper refers to the field performance of the tractor-seed drill system and the seed spacing uniformity with reference to three precision drills with 4, 6 and 8 sowing units, respectively. The tests have been conducted using graded maize and sugar beet seeds, according to ISO 7256-1:1984 standard, under three speed conditions (5.0, 6.5 and 8.0 km h^{-1}). The seed drills showed high values of the quality of feed index (> 90%) even at the higher speed. The multiples index and the miss index were very low.

ABSTRACT
Le seminatrici pneumatiche di precisione migliorano significativamente la competitività delle aziende agricole, in termini di qualità della semina e resa del raccolto. Questo lavoro ha verificato le prestazioni in campo dell'accoppiamento trattore-operatrice e l'uniformità di deposizione del seme di tre seminatrici dotate, rispettivamente, di 4, 6 e 8 unità di semina. I test sono stati condotti a tre velocità di semina (5.0 ,6.5 e 8.0 km h^{-1}) in accordo allo standard ISO 7256-1:1984, utilizzando sementi certificate di mais e bietola. Le seminatrici testate hanno mostrato elevati valori dell'indice delle deposizioni regolari (> 90%), anche alla velocità più elevata. Gli indici delle deposizioni multiple e delle deposizioni mancate sono risultati molto bassi.

INTRODUCTION
In a background of increasing input of high technology solutions in agricultural mechanization, the diffusion of pneumatic precision seed drills for the sowing of spring-summer crops, significantly contributes to improve the competitiveness of farms by ameliorating sowing quality and yield *(Gondal et al., 2017)*. The productivity of crops like maize and sugar beet depends not only on the cultivation method, but also on the respect of the plant investment per area unit, which is realized through the spaced sowing. For this reason, the efficiency and the proper use of precision seed drills is a crucial point *(Fanigliulo and Pochi, 2011)*. The optimal planting density per unit area increases the yield of agricultural products while preventing the overuse of such inputs as seeds, water, fertilizers, pesticides, and herbicides. Especially for sugar beet, under suitable plant spacing in vertical and horizontal levels, the roots can grow to the size requested from the sugar industries and they can fill the row, without reducing the space available to the adjacent roots *(Findura et al., 2008)*.

The aim of the precision seed drill manufacturers and researchers is to improve seed drill design and the accuracy of seed placement, often electronically controlled *(Karimi et al., 2019)*, according to cultivation standard requirements. The main objective of precision seeding is ensuring that the seeds are put at the desired depth and spacing within the row. Soil pulverization *(Fanigliulo et al., 2018)*, seed metering device *(Cujbescu et al., 2021)*, sowing depth *(Karayel and Özmerzi, 2008)* and sowing speed *(Vučajnk et al., 2020)*, represent the main factors affecting performance of seed drills. As the sowing speed increases, the sowing accuracy decreases because of the enhanced seed bounce and rolling effect occurring even with reduced distance between seed drop tube and the furrow. Also, the seed drop tube condition, new or worn, influence the seed spacing uniformity *(Kocher et al., 2011)*.

Regularity of seed spacing can also be affected by the vibrations induced by excessive soil surface roughness, particularly at high sowing speed, and by specifications of the seeding unit (type of seeder opener, final speed of the seed at the outlet from the seeding disc, acceleration of the seeding unit in vertical direction).

The distance between plants within a row could be influenced by some factors, such as failure of dropping seed, multiple seeds dropped at the same time, failure of seeds to emerge, and the variability of seed placement around the drop point *(Kachman and Smith, 1995)*. In compliance with the ISO 7256-1:1984 standard (ISO, 1984), CREA, developed a test system and a series of devices and instruments aimed at evaluating the precision seed drills field performance, the qualitative aspects of the sowing and the dust drift of dressed seed from the machine vacuum fan *(Pochi et al., 2015a; Biocca et al., 2015; Biocca et al., 2017),* potentially harming for the health of honeybees and agricultural workers (*Pochi et al., 2015b; Biocca et al*., 2019). The CREA test system represents an instrument useful to the manufacturers that can quantify the performance of their products, the effects of some modifications and the differences with other machines. The tests provided detailed information about the performances of the machines, allowing their comparison. Moreover, the system has the function to provide the users with the elements necessary for a correct choice of the machine, depending on their sowing requirements.

This paper reports the results of tests aimed at the comparison of the field performance of three precision seed drills, equipped with double furrow-opener disks, respectively with 4, 6, 8 sowing units. These machinery are widespread in Northern and Central Italy and have different mechanic solutions of the seed metering device.

MATERIALS AND METHODS

The dynamic-energetic behaviour of the tractor-seed drill system and the quality of sowing were tested. The tests were carried out using graded maize and sugar beet seeds, evaluating the accuracy of the single seed metering mechanism, in terms of distance among the seeds along the furrows, at three working speed values (5.0, 6.5 and 8.0 km h^{-1}), representative of normal sowing conditions. In the field tests, three rear semi-mounted pneumatic precision seed drills (indicated as A, B and C) with a different number of sowing units (4, 6 and 8) were used (Fig. 1). In each seed drill, the deposition of a single seed at a predefined distance was operated by tractor's power-take-off. Table 1 shows their technical characteristics and their dimensions.

Fig. 1 - The precision drills used in the tests.
(A) with four sowing units; (B) with six sowing units; (C) with eight sowing units

Table 1

Main technical characteristics of the tested precision seed drills

Technical data	Seed drill A		Seed drill B		Seed drill C	
	Maize	Sugar beet	Maize	Sugar beet	Maize	Sugar beet
Total width in sowing position (m)	3.0		4.5		6.0	
Sowing units (n)	4		6		8	
Pneumatic wheel drives (n)	2		2		4	
Hopper capacity (dm^3)	37		37		32	
Seed disks diameter (mm)	240		240		220	240
Number of gathering holes (n)	24	36	24	36	26	36
Hole diameter (mm)	4.5	2.5	4.5	2.5	4.75	2.10
Mass with empty hoppers (kg)	840	796	1415	1349	1600	1499

Each sowing unit consists of a hopper, a single-seed metering mechanism and of the devices devoted to furrow opening and closing and to sowing depth adjustment. An articulated parallel link hitch connects the sowing units to the main frame, allowing the vertical movements due to the soil unevenness and keeping the sowing depth constant. The bottom of the hopper directly communicates with the vertical sowing disk that shows, on its peripheral part, equidistant holes with diameter slightly smaller than the seeds. A vacuum fan provides each sowing unit with the required vacuum. Flexible pipes starting directly from the fan have the function of making uniform the air flow created by the vacuum in all sowing units. The furrow is opened by a double disk equipped with a soil scraper and a coulter. A clod pusher precedes the disks to remove the biggest clods from the row. The sowing depth is controlled by two lateral steel wheels with rubber coating and soil scraper. In seed drills B and C, a small seed-presser wheel after each sowing unit ensures the contact between soil and seeds, operating the seed compression immediately after its deposition. In these seed drills, the furrow is closed by a couple of convergent small wheels. The precision seed drills were operated by a 4WD tractor (Landini Legend 145, Reggio Emilia, Italy) with nominal power of 110 kW and total mass of 6420 kg. The P.T.O. speed was 540 min^{-1} corresponding to an engine speed of 1.944 min^{-1}. All tests were performed with diesel fuel in compliance with the EN 590, which was always provided by the same supplier. Consequently, its quality was assumed to be constant, with a Low Heating Value of 42.7 MJ kg^{-1}. Before sowing tests, the tractor's engine performance was verified at the dynamometric brake that provided the updated characteristic curves of the engine *(Pochi et al., 2013)*. After field tests, the tractor was connected again to the dynamometric brake to reproduce the work conditions: the engine speed was set on the same values adopted at the start of each test. Then, the engine load was increased in such a way that the resulting engine speed reductions were equal to the average speeds measured during the field test. This method provided the average values of the total torque and power required to the engine and the corresponding fuel consumption.

The efficiency of the seed metering mechanism was evaluated in the experimental farm of CREA in Monterotondo (Rome, Italy; 42°5'51.26"N; 12°37'3.52"E; 24 m a.s.l.), on flat surface plots (< 1% slope) classified as silty-clay (clay 543 g kg^{-1}, silt 434 g kg^{-1}, sand 23 g kg^{-1}) according to the USDA soil classification system. The soil was previously ploughed at medium depth and subsequently pulverized by means of a power harrow equipped with a packer roll *(Fanigliulo et al., 2016)*. Tests were conducted at near optimum soil moisture for tillage and sowing. Table 2 shows the main characteristics of the test field.

Table 2

Physical-mechanic characteristics of the soil

Moisture contents at the depth range of 0-0.2 m (%)	18.6
Dry bulk density at the depth range of 0-0.2 m (g cm^{-3})	1.21
Clod-breaking index	0.85
Surface roughness index	2.34

The quality of the seedbed was evaluated through the determination, before the sowing, of the clod-breaking index (CBI) and of soil surface roughness index (SRI) *(Fanigliulo et al., 2021)*. The cloddiness was measured digging a 0.5 m side square trench to the working depth. The soil aggregates were removed from the trench avoiding any manipulation and left to dry for at least 20 min. Then they were divided into six size classes by means of hand-operated standard sieves and weighed. An index (I_{ai}), ranging from 0 for the biggest class to 1 for the smallest class, was attributed to each class. The cloddiness results as the percent of each size class mass referred to total mass of the sample.

From the cloddiness, the CBI (I_a) is calculated as follows:

$$I_a = \sum_{i=1}^{6} \frac{M_i \cdot I_{ai}}{M_t} \text{ [mm]} \quad (1)$$

where:

$M_i \cdot I_{ai}$ is the product of the index assigned to a clod size class and the mass (kg) of ground belonging to the same class; M_t is the total mass of the sample (kg).

The SRI was calculated as the standard deviations (σ) of the series of data provided by an in-house designed profile-meter *(Fanigliulo et al., 2020)*: a laser sensor, moving along a horizontal rail, measures its distance from the soil surface at steps of 10 mm. A personal computer collected and processed the data, by means of a software program (in Microsoft Visual Basic 6.0) which controls the movement of the laser probe and the sampling rate per unit of distance. This determination was made after the passage of the power harrow. The tests on the performance of the tractor-operating machine system have been performed according to ENAMA test protocol *(ENAMA, 2003)*. To find the correct working parameters (sowing speed and gear box ratio; P.T.O. and vacuum fan speed; air depression value, etc.) some preliminary tests were carried out. For each tested regulation, three replications were carried out, determining the following operative parameters: actual working time, width and depth of sowing; sowing speed; P.T.O. torque, speed and power; force of traction required by the sowing machines and corresponding power under the measured sowing speed conditions; tractor's slip; fuel consumption. Each measurement refers to a 100 m reference working distance, within the 150 x 20 m experimental fields.

The data of the mentioned parameters were collected by an integrated system based on two units, a field unit and a support unit *(Fanigliulo et al., 2004)*. The tractor (equipped with sensors and a personal computer with a PCI card for real time data acquisition and an LCD monitor) and a photocell system (placed in each test plot and indicating the start and stop of the test) represent the field unit. The sensors' signals were recorded at a scan rate of 10 Hz. The support unit consists of a van equipped as a mobile laboratory which is parked on the field border during the tests. Its PC communicates with the field unit's PC by means of a radio-modem system, exchanging data and allowing to monitor the behaviour of critical parameters and the efficiency of the instruments. The sensors used in the tests consisted of a 500 Nm full scale torque meter mounted on the tractor P.T.O. shaft, measuring the torque and speed during the work (to calculate the required P.T.O. power); a digital encoder measuring the number of revolutions of the tractor rear wheels on a reference distance (to calculate its peripheral velocity and the slip); a 49 kN full scale load cell, fitted in a suitable drawbar connecting a dynamometric vehicle and the tractor-seed drill system in neutral, pulled at the same sowing speed (for the measurement of the force of traction). The three precision drills underwent sowing tests using certified maize and sugar beet seeds. The main characteristics of the seeds are reported in Table 3.

Table 3

Physical characteristics of maize and sugar beet seeds utilized during the field tests

Characteristics	Maize	Sugar beet
Seed emergence (%)	92	80
Seed purity (%)	99	97
Average calibre (mm)	GR2	4.1
Cultivation cycle length (Days)	135	-
Bulk density (g dm^{-3})	801	480
Thousand seed mass (g)	445	28.2

The three machines have been set to carry out the sowing according to the data reported in the Table 4.

Table 4

Sowing conditions and seed drills setting

Seed	Maize			Sugar beet		
Seed drill	A	B	C	A	B	C
Mass of seed with full hoppers (kg)	115	173	224	71	107	123
Distance between rows (m)	0.75			0.75		
Theoretical seed spacing (mm)	175	190	173	120		
Investment (seeds m^{-2})	7.6	7.0	7.7	11.1		
Theoretical seed distribution (kg ha^{-1})	33.9	31.2	34.9	3.1		
Sowing depth (mm)	40			20		
Sowing speed (km h^{-1})	6.4–8.1	6.6-8.3	6.6-8.2	4.9-8.0	5.1-8.1	4.9-8.0

The air depression for maize and sugar beet seeds, measured by a vacuum gauge installed on each seed drill, was set on the values indicated by the manufacturers on the instruction manuals. As to the evaluation of the sowing quality, according to the ISO 7256-1:1984 standard, the actual spacing along the row between adjacent seeds must be determined and related to the theoretical spacing indicated by the manufacturer in the calibration chart. After the sowing, seeds spacing was measured on random row portions 20 m long, by measuring the distance between contiguous seeds in the furrow. Referring to the theoretical spacing, the actual spacing measurement is classified in the mentioned ISO standard as: DS (double sowing), when it is 0 to 0.5 times the theoretical spacing; AS (correct sowing), when it is 0.5 to 1.5 times the theoretical spacing; MS (missing sowing), when it is higher than 1.5 times the theoretical spacing. Since the actual seed spacing is the key-parameter in the evaluation of a precision drill, its deviations from the theoretical spacing values underwent the statistical test ANOVA (analysis of variance). The test was carried out separately for maize and sugar beet datasets, considering as variability factors: three machines, two speeds, two hoppers for each machine (one lateral hopper and one central hopper) and their interaction. The test was based on five replicates, each with ten values of deviation.

The percent frequency of measurements occurring in each class allows to define several quality indices characterizing the machine, as the multiple index, the quality of feed index, the miss index and the precision sowing index (CS), ratio between the standard deviation of AS measurements and the theoretical spacing. These indices measure the degradation of the performances within the target range. Low values of DS, CS, and MS and high AS values indicate good performance of the machine. According to the standard, at least 250 depositions on the same row must be considered, repeating the counting on three sowing units (two lateral and one central sowing unit). Lastly, the uniformity of transversal distribution was evaluated for all the sowing units of the tested machines. The quantity of seed distributed by each of them, along the reference distance, was properly collected and weighted, providing the behaviour of the transversal distribution and the transversal unevenness index. Moreover, the total mass of seeds collected during each replication allowed the calculation of the actual seed dose (kg ha^{-1}) and, by referring to the theoretical dose, the efficiency of distribution (coefficient of irregularity, %). Basing on the above indices relating to the quality of sowing, the performances can be synthetically judged as “insufficient”, “sufficient”, “good”, and “excellent”.

RESULTS

The data of the dynamic-energetic performances of each tractor-sowing machine system are reported in Table 5. The results of the measurements aimed at evaluating the quality of sowing are reported in Table 6.

Table 5

Average values of the parameters describing the technical performance of each tractor-seed drill system

Parameters	Seed drill A				Seed drill B				Seed drill C			
	Maize		Sugar beet		Maize		Sugar beet		Maize		Sugar beet	
Actual sowing speed (km h^{-1})	6.4	8.1	4.9	8.0	6.6	8.3	5.1	8.1	6.6	8.2	4.9	8.0
Actual sowing capacity (ha h^{-1})	1.9	2.4	1.5	2.4	3.0	3.8	2.3	3.6	3.8	4.9	3.0	4.8
Operative sowing capacity (ha h^{-1})	1.1	1.3	0.9	1.3	1.7	2.0	2.5	2.0	3.3	3.7	2.4	3.5
Fuel consumption per hour (kg h^{-1})	6.4	6.9	4.8	6.4	7.5	8.3	6.6	7.4	11.8	12.6	14.3	15.8
Surface unit fuel consumption (kg ha^{-1})	3.3	2.8	3.2	2.6	2.5	2.2	2.8	2.0	3.1	2.6	4.9	3.3
Average force of traction (kN)	2.2	2.4	1.8	2.1	3.0	3.2	2.5	3.0	5.7	6.2	5.2	6.0
Power required for the traction (kW)	3.9	5.4	2.4	4.8	5.5	7.4	3.5	6.7	10.5	14.1	7.1	13.4
Specific resistance to traction (kN row^{-1})	0.5	0.6	0.4	0.5	0.5	0.5	0.4	0.5	0.7	0.8	0.6	0.8
Average P.T.O. speed (min^{-1})	516	509	402	395	533	523	440	420	503	506	455	435
Average torque at the P.T.O. (daNm)	1.7	2.0	1.9	1.7	3.0	2.6	3.2	2.9	6.9	7.3	6.6	7.7
Average power at the P.T.O. (kW)	0.9	1.1	0.8	0.7	1.7	1.4	1.5	1.3	3.6	3.9	3.1	3.5
Slip (%)	1.6	2.3	1.5	2.3	2.2	2.5	1.8	2.4	3.3	3.6	1.9	3.3
Power losses for slip (kW)	0.2	0.4	0.1	0.3	0.3	0.4	0.2	0.4	0.4	0.6	0.3	0.9
Total power required (kW)	4.8	6.4	3.2	5.5	7.1	8.8	5.0	8.0	14.6	18.6	10.5	17.8
Tractor’s total engine power (kW)	9.8	14.3	7.6	15.0	16.3	22.1	15.9	20.1	28.2	35.5	19.3	34.3
Energy per surface unit (MJ ha^{-1})	18.5	21.5	18.8	22.7	20.1	21.5	25.0	20.1	25.6	26.0	23.7	25.8

Table 6

Uniformity and accuracy indices resulting from the tests with the precision drills

Technical parameters	Seed drill A				Seed drill B				Seed drill C			
	Maize		Sugar beet		Maize		Sugar beet		Maize		Sugar beet	
Average seed spacing (mm)	182	185	138	129	205	216	146	138	196	179	145	139
Coefficient of Variation	21.4	26.5	40.2	24.9	14.4	15.6	36.5	22.0	16.6	29.1	35.4	23.6
Average depth of seed placement (mm)	38.1	41.2	13.8	12.9	40.9	41.8	14.6	13.8	41.0	42.1	13.9	13.2
Transversal unevenness index (%)	2.1	2.4	2.6	0.9	0.6	3.7	5.9	6.1	0.9	1.6	6.6	6.9
Coefficient of irregularity (%)*	-0.9	-6.5	-3.9	-2.4	-3.6	-5.1	-8.3	-7.3	-5.9	-6.4	-8.5	-8.1
Multiple index (%)	1.0	0	2.5	0	0	0	0.4	0	0	2.3	1.7	1.3
Quality of feed index (%)	96.1	95.2	82.3	93.8	98.8	97.9	84.0	93.5	95.1	90.4	85.3	90.6

Technical parameters	Seed drill A				Seed drill B				Seed drill C			
	Maize		Sugar beet		Maize		Sugar beet		Maize		Sugar beet	
Miss index (%)	2.9	4.8	15.2	6.2	1.2	2.1	15.6	6.5	4.9	7.3	13.0	8.1
Precision sowing index (%)	15.0	18.2	19.3	18.3	12.1	12.5	20.0	17.5	19.2	22.4	19.9	17.3

* *Referring to the theoretical dose*

Among the data reported in Table 5, modest values of specific resistance to traction can be noticed, with corresponding low traction power requests. Tractor's slip and fuel consumption values are normal for this typology of machines. The dynamic and energetic parameters clearly increase with speed, for all machines that, because of the reduced run-out time (turning, manoeuvres, hoppers' refills), showed high sowing capacity.

Maize sowing test

The actual sowing depth was similar to the pre-set value, as some differences can be observed between theoretical and actual seed spacing (4.1% and 5.9% for seed drill A; 7.9% and 13.6% for B; 13.0% and 3.6% for C). According to the results of the ANOVA carried out on the deviations of actual seed spacing from theoretical seed spacing (Table 7), said differences seem mostly caused by the factor "machines" (*p = 0.05*) probably due to their different design, type of sowing disks, number of hoppers. The differences relating to the speed and hopper's position were not significant. However, those due to the interaction of factors were significant (p = 0.05).

Table 7

Results of the ANOVA carried out on the deviations of the actual spacing values from the theoretical spacing values (Table 4) observed after the sowing of maize seed with the three pneumatic precision drills

Variability factors	Deviance	Degree of freedom	Variance	F Calculated	Probability		
					p = 0.05	p = 0.01	p = 0.001
Replicates	15.60	4	3.90	0.27	2.37	3.32	4.62
Seed	87.5	2	43.74	3.08	3.00	4.61	6.91
Speed	7.8	1	7.81	0.55	3.84	6.63	10.83
Hoppers	2.9	1	2.87	0.20	3.84	6.63	10.83
Interaction	270.2	11	24.57	1.73	1.72	2.20	2.68
Error	8384.9	591	14.19	-	-	-	-
Total	8768.9	599	-	-	-	-	-

Based on the results of the ANOVA, the minimum significant differences, MSD, between the average deviations of the three machines, reported in Table 8**,** indicate that only the difference A-B is significant (p=0.01) and is mostly responsible of the variability observed in the ANOVA among seed drills. This means that the seed drill A has a smaller average deviation than B from the theoretical distance between the seeds. A can be considered better than B, but not better than C, just as C cannot be considered better than B, despite its smaller mean deviation.

Table 8

Minimum Significant Differences between the means relating to the results of the ANOVA reported in Table 7

Mean spacing			Difference between means			t values		
A	B	C	A-B	A-C	B-C	p = 0.05	p = 0.01	p = 0.001
0.843	1.763	1.157	**-0.920**	-0.315	0.605	1.645	2.326	3.090
Standard error of the difference between two means						0.377		
Minimum Significant Differences (MSD)						0.620	0.876	1.164
Significance						A-B	A-B	n.s.

Increasing the sowing speed, the actual seed distribution decreased from 33.5 to 31.5 kg ha^{-1} for the machine A, from 32.5 to 31.9 kg ha^{-1} for the machine B and from 34.8 to 32.6 kg ha^{-1} for the machine C, with a variation of 5.8, 1.7 and 6.2%, respectively. Considering the transversal unevenness index, as it shows very low values in all conditions, it can always be classified as "excellent".

The coefficient of irregularity always resulted “excellent” in all tests but two: for the machines A and C at 8 km h^{-1} it has been judged “good”. A similar behaviour has been observed for the quality of feed index, the values of which resulted “excellent” for the machine B, as they were “good” for the machine A. For the machine C, the values resulted “acceptable” at lower speed and “insufficient” at 8.2 km h^{-1}. The histograms of Figures 2, 3, and 4 show the distribution of frequency of the seed spacing values.

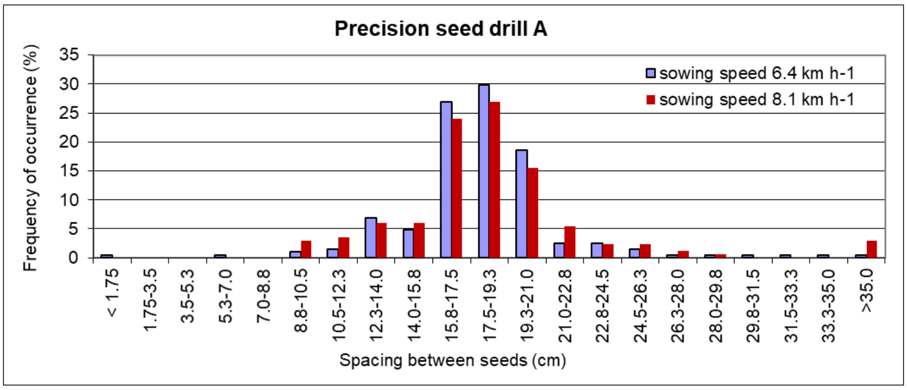

Fig. 2 - Frequency distribution of the seed maize spacing values for the machine A (theoretical value: 17.5 cm)

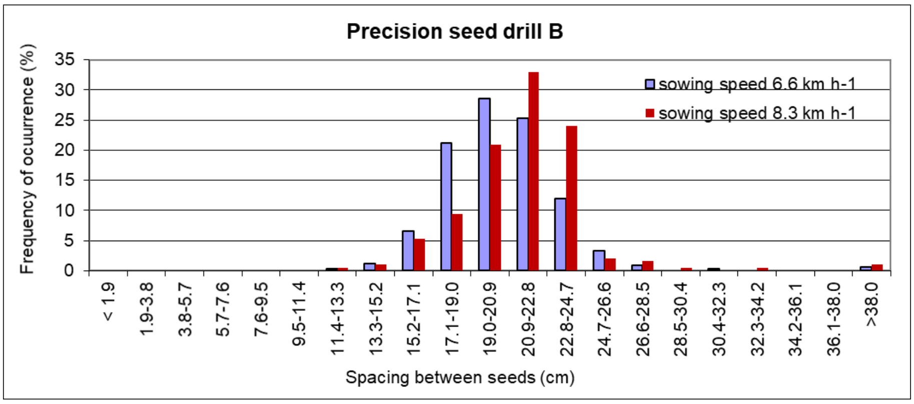

Fig. 3 - Frequency distribution of the seed maize spacing values for the machine B (theoretical value: 19.0 cm)

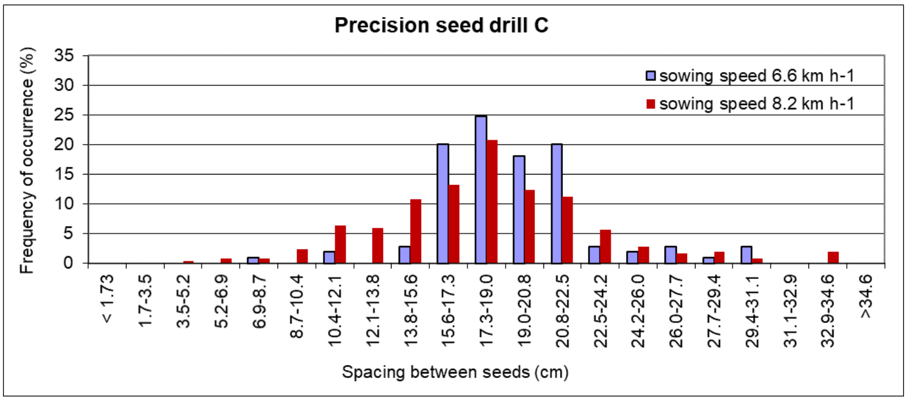

Fig. 4 - Frequency distribution of the seed maize spacing values for the machine C (theoretical value: 17.3 cm)

It can be noticed that, in the class corresponding to the theoretical spacing, the variability increased with the speed and the frequency of the values decreased. The highest frequencies inside the theoretical spacing classes have been observed for the machine A, under both sowing speed conditions. The histograms of the machine B also showed a lower number of classes than A and C: considering a ± 30 mm interval around the theoretical spacing, the depositions occurred in it have been, for A, B and C, respectively 80.4%, 81.5% and 65.7% at the lower speed and 72.5%, 68.6% and 57.2% at the higher speed.

Sugar beet sowing test

As observed for maize, also in this case the actual sowing depth was similar to the pre-set value. Some differences occurred between theoretical seed spacing (Table 4, constant for the three machines) and actual seed spacing (15.3% and 7.3% for A; 21.9% and 14.9% for B; 20.4% and 15.6% for C).

The ANOVA carried out on the deviations of actual seed spacing from theoretical seed spacing (Table 9) did not show any significant differences in the deviations due to the considered variability factors.

Table 9

Results of the ANOVA carried out on the deviations of the actual spacing values from the theoretical spacing values (Table 4) observed after the sowing of sugar beet seed with the three pneumatic precision drills

Variability factors	Deviance	Degree of freedom	Variance	F Calculated	Probability		
					p = 0.05	p = 0.01	p = 0.001
Replicates	158.01	4	39.50	2.03	2.37	3.32	4.62
Seed	27.3	2	13.63	0.70	3.00	4.61	6.91
Speed	12.2	1	12.16	0.63	3.84	6.63	10.83
Hoppers	15.2	1	15.23	0.78	3.84	6.63	10.83
Interaction	229.2	11	20.83	1.07	1.72	2.20	2.68
Error	11493.6	591	19.45	-	-	-	-
Total	11935.4	599	-	-	-	-	-

Increasing the sowing speed, the actual seed distribution increases from 3.01 to 3.06 kg ha^{-1} for the machine A, from 2.87 to 2.90 kg ha^{-1} for the machine B and from 2.86 to 2.88 kg ha^{-1} for the machine C, with a variation respectively of 1.6, 1.0 and 0.4%. Considering the transversal unevenness index and the coefficient of irregularity, since they show very low values in all conditions, they can always be classified as excellent for seed drill A and good for seed drills B and C. A similar behaviour was observed for the quality of feed index values that resulted acceptable at 8.0 km h^{-1} for all machines, as it was not sufficient at lower speed. The histograms of Figures 5, 6, and 7 show the frequency distribution of the seed spacing values.

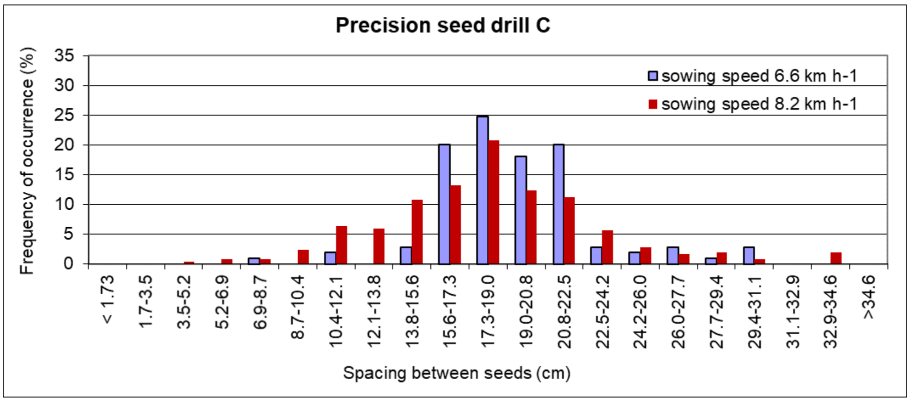

Fig. 5 - Frequency distribution of the sugar beet seed spacing values for the machine A

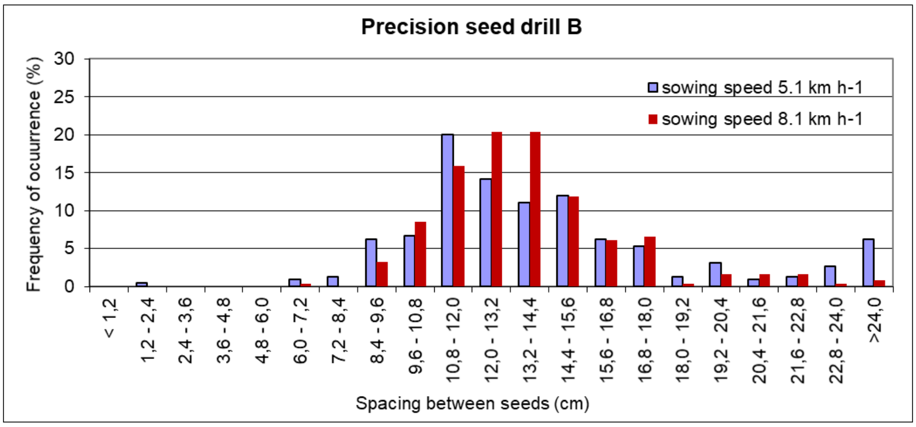

Fig. 6 - Frequency distribution of the sugar beet seed spacing values for the machine B

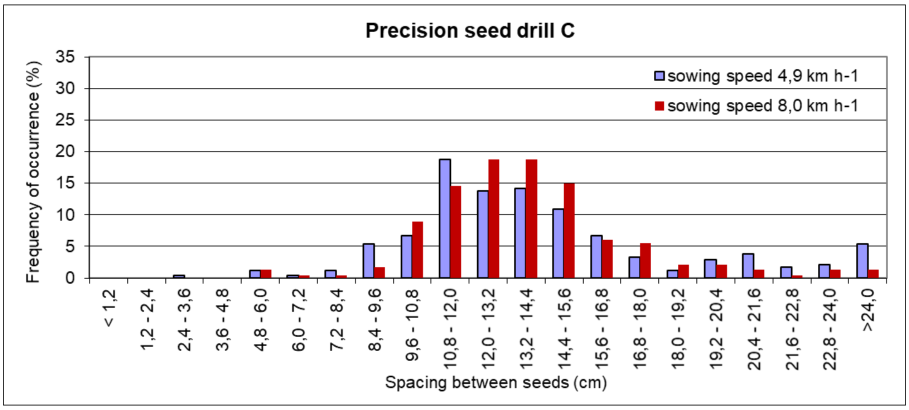

Fig. 7 - Frequency distribution of the sugar beet seed spacing values for the machine C

The variability decreases with the sowing speed and the frequency of values in the class corresponding to the theoretical spacing decrease except for the seed drill A. The highest frequencies inside the theoretical spacing classes were observed for the machine A, under both speed conditions. The histograms of the seed drill A also showed a lower number of classes than B and C: considering a ± 24 mm interval around the theoretical spacing, the depositions occurred in it have been, for A, B and C, respectively 40.5%, 34.2% and 32.5% at the lower speed and 38.1%, 36.3% and 33.3% at the higher speed.

CONCLUSIONS

During the field experiments of sowing of maize and sugar beet, carried out according to ISO 7256-1:1984 standard, we compared three pneumatic precision seed drills with a different number of sowing units (4, 6 and 8) and under two sowing speed conditions. The tested seed drills showed good performances in sowing operations, which are strictly connected to the optimal setting of the seed selector of the metering system and to the correct choice of disks with the most suitable hole diameter. The sowing speed and the sowing width represent the main factors affecting precision seed drill performance. As they increase, the vibrations induced by any soil unevenness could affect the uniformity of seed spacing. As for the sowing capacity, it was found to be fair due to the good manoeuvrability of the machines and the ease of filling the hoppers. With full hoppers and at the highest speed, the sowed surfaces were about 3.8, 5.6, 6.3 ha for maize and 23.2, 36.7, 42.7 ha for sugar beet, respectively for the machines A, B and C. Moreover, the accuracy of the devices regulating the pressure of burying allowed to maintain constant sowing depth, corresponding to the pre-set values. The increasing of sowing speed seems to induce opposite results in the two crops: in fact, the quantity of maize seed distributed per hectare decreased, while the sugar beet seed quantity per hectare increased. The missing deposition value (MS) was affected in a similar way. This was probably caused by an irregular seed feeding due to a not optimum time of contact between seeds and disk, also due to the different size and mass of the tested seeds. No effect was observed on the multiple depositions (DS). Consequently, the average actual spacing was increased for all machines and particularly for B. The good values of quality-of-feed index testify the accuracy of the distribution system and its efficiency even at higher speed for seed drill (beyond 90%). The precision sowing index observed in the tests ranged from 12.1% up to 22.4% in maize sowing, and from 17.5% up to 20.0% in sugar beet sowing, indicating that the spacing values were uniformly distributed within the target range. As to the frequency distribution of the spacing values, the machine A showed the best performance. This can be explained by the presence, in each metering system, of the anti-filling-up plate aimed at avoiding multiple depositions.

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