Performance evaluation of a cyclone to clean the air exiting from pneumatic seed drills during maize sowing

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Abstract

Seed dressing that controls pests by the application of small doses of neonicotinoids directly on the seed is used on a large variety of crops. Although this system is efficient and inexpensive, in recent years it has been banned because small amounts of dust abraded from the seed coating can be released into the atmosphere by sowing machines and which kills non-target insects including honey bee. Bayer Crop Science® has developed a device to clean the air at the exit of the drill's fan (patented as SweepAir®). This system is able to separate the dust from the exhaust airflow and convey it into the soil while the cleaned air is returned to the atmosphere. This paper reports experimental tests on the performance of this system.

The tests showed that the cyclone system effectively separated 99.4% of the inert material, and it did not negatively impact drill performance. The tested kit reduced the contaminated superficial soil area by close to 100% and eliminated dust drift because the abraded seed dust was effectively inserted into the soil. In addition, this system can improve operator and environmental safety because the external surface of the drill was not contaminated by pesticides.

Keywords

Neonicotinoids, treated seeds, pneumatic drills, pesticides dispersion, SweepAir® kit

1. INTRODUCTION

Toxic substances can be released into the atmosphere as a result of agricultural processes, especially those linked to fuel consumption during cultivation (Blengini and Busto, 2009; Snyder et al., 2011; Safa and Samarasinghe, 2012) and to the use of pesticides (Lichiheb et al., 2014).

Seed dressing that controls pests by the application of small doses of pesticides directly on the seed is used on a large variety of crops (Elbert et al., 2008). Although this system is efficient and inexpensive, in recent years it has been restricted for some chemicals (e.g. neonicotinoids) because small amounts of dust abraded from the seed coating can be released into the atmosphere by sowing machines which kills insects that are not harmful to crops including important benefits insects including honey bees (Nuyttens et al., 2013).

Because the seed coating is abraded inside the seeding element, all seed drills produce a fine dust that could contaminate the environment. This is especially true for pneumatic drills, where an air stream generated by a fan is necessary to create a vacuum in the drill's sowing element. The air stream can blow solid dust particles detached from treated seeds towards areas adjacent to the field (Altmann, 2003; Greatti et al., 2003; Schnier et al., 2003; Greatti et al., 2006; Baldassari et al., 2008; Girolami et al., 2009).

Various authors have studied this phenomenon and have measured dust emission or dust drift potential under controlled and repeatable conditions by different methods (Giffard and Dupont, 2009; Biocca et al., 2011; Balsari et al., 2013;Manzone et al., 2014). Based on those results, drills were classified according to drift risk (Rautmann et al., 2009; Herbst et al., 2010).

In the past few years, several technical solutions applicable to pneumatic drills were developed to address this problem, but none of them was able to completely eliminate dust dispersion. These devices were able to contain 80% of the dust dispersed within the drill contour (Manzone et al., 2014).

Adopting some precautions during sowing activities also can reduce pesticide dispersion. Balsari et al. (2013) report that environmental contamination due to maize seed dressing can be reduced if pneumatic drills use lower fan revolution speeds. If the fan revolution speed is decreased by 1000 rev min^{-1} (corresponding to decreasing the PTO by 100 rev min^{-1}), airflow rate and fan air speed are decreased by 30%, significantly reducing the surface contaminated by the seed dressing material and also guaranteeing necessary depression of the seeding elements.

Previous technical solutions directed the exhaust airflow from the drill outlet toward the soil but did not eliminate the risk of environmental contamination. Therefore, Bayer CropScience® has developed a device to clean the air at the exit of the drill's fan (patented as SweepAir®). This system is able to separate the dust from the exhaust airflow and convey it into the soil while the cleaned air is returned to the atmosphere (Vrbka et al., 2014; Chapple et al., 2014). This paper reports experimental tests on the performance of this system.

2. MATERIALS

2.1. The tested system

The main component of the tested system is the cyclone, a device able to separate dust from the airflow. Exhausted air from the pneumatic drill's fan is conveyed through a "primary pipe" with an 85 mm internal diameter that connects the fan outlet to the cyclone inlet. The pesticide dust is separated from the airflow in the cyclone. The clean air is moved upward in the cyclone and emitted into the atmosphere through a "secondary pipe" with a 150 mm internal diameter. The dust is conveyed downwards in the cyclone and then deposited into the soil by the furrow system. A rotary vacuum valve is installed between the cyclone and the furrow system. This valve ensures that the cyclone system properly functions and guarantees that the collected dust is discharged only when the furrow is in the soil (Fig. 1).

2.2. Drill used in the trials

Trials were conducted with a conventional pneumatic drill normally used for maize sowing in Europe (Gaspardo®MARTA). During the tests, the drill was configured with four and six seeding elements and with fertilizer hoppers (Fig. 2). The drill was set to sow 75,000 seed ha^{-1} with a distance between the seeding elements of 0.75 m (Table 1). During the test, in order to fix the tested kit to the drill, a specific support able to maintain in vertical position the cyclone was provided on its frame. Rotary valve was moved directly by the shaft used to power all seeding elements. This movement was held in place by a steel chain.

3. METHODS

Two series of tests were performed to assess the system's performance. Firstly, the efficiency of the system was determined: 1) cyclone dust separation efficiency, 2) vacuum

rotary valve life and 3) furrow system efficiency. Second, the influence of the system on the drill performance was evaluated: 4) fan airflow rate and vacuum level inside the seeding elements. Tests 3 and 4 were performed with and without the kit on the sowing machine.

Tests were performed without dressed maize seeds but using a defined tracer amount to simulate the seed dressing dust. This choice allowed elimination of the variability in the amount of dust abraded from the coated seeds during each test and to have reproducible test conditions for all the trials.

3.1. Cyclone dust separation efficiency

The cyclone dust separation efficiency was evaluated using a mass balance method. The difference between the mass of tracer inserted into the kit and the amount intercepted by the cyclone system was measured. Because an inert material was used, the tests could be conducted without specific operator safety precautions.

Wheat flour “00”, was used as proposed by Balsari et al. (2013) because this material has particle sizes similar to seed dressing material in the exit from the drill’s fan (Table 2) (Balsari et al., 2013).

This result had been obtained by analysing the particle sizes of the dust material expelled from the air outlets of the drills when using dressed maize seeds (KWS® and Pioneer®) and of wheat flour “00”. To collect the dust material expelled from seed drills a “cyclone vacuum cleaner” (characterized by vacuum air flow rate of 260 $m^3 h^{-1}$ and 97% efficiency separation) was used and the particles size analysis was made through an image analysis system (Image Pro Plus®). In order to select the inert material for simulating the dressed

maize powder, tests were made using wheat flour “00” (a cheap and widely available material) and considering the Volumetric Median Diameter (VMD) value. For each material (maize seed dressing and wheat flour “00”), the diameters of the granules were determined using the specific software Image Pro Plus® on five samples of at least 2000 particles obtained from 50 images acquired by a Epix Sv 5 C10 5 Mpixel camera with a 1.4 µm $pixel^{-1}$ resolution equipped with a Nikon® AF Micro Nikkor 60 mm lens.
Statistical analysis (ANOVA) showed that the wheat flour “00” had physical characteristics very similar to the maize seed dressing material and therefore it was used to assess the dust dispersion from the sowing machines (Table 2).

During the tests, a partial vacuum of 42 mbar was maintained inside the seeding element, which Bragatto (2008) considers optimal for correct maize sowing. One hundred grams of wheat flour “00” (3 g per min) was introduced into the inlet air stream of the cyclone. This is approximately 100 times higher than the potential, worst-case amount of abraded dust (3 g per 100 kg of treated seeds) (Heimbach, 2012). The efficiency of the cyclone was determined with a higher dust rate because during normal sowing activities the drill can also ingest soil dust.
All wheat flour “00” amounts were measured with an accuracy of 0.1 g. Tests were conducted with and without seeds in the hopper. Note that without seeds on the disc of the seeding elements, the airflow rate exiting the drill’s fan is increased by approximately 130% (Balsari et al., 2013). For this reason, during sowing activities, if the seeds are not present in the seeding elements, the cyclone must be able to effectively clean a larger airflow. Therefore, tests were conducted using airflow rates of 210 and 480 $m^3 h^{-1}$. The system was run for 5 min both before and after insertion of the wheat flour “00” to ensure that the cyclone was fully operational.

A specially designed, electrically driven piston-cylinder test system with a 40-mm internal diameter was used to introduce the tracer into the primary pipe that feeds the cyclone. This system inserted the wheat flour “00” at a rate of 3 g per min. To reduce the risk that the dust would deposit inside the primary pipe, the wheat flour “00” insertion device was placed 60 mm from the cyclone inlet (Fig. 2).

The tests were conducted ten times and the data were processed using SSPS 2014.

3.2. Vacuum rotary valve life

The vacuum rotary valve life was tested. The efficiency of this component is extremely important because if the valve does not keep a hermetic seal, pesticide particles may leak. The valve tightness was evaluated with compressed air in accordance with UNI 7129/08 (2008), a standard used for methane civil plant testing. In particular, the standard specifies that the inlet side of a valve connected to an air compressor is able to maintain a pressure of 500 mbar. After a stabilization time of 15 min, the air leakage was determined using a water manometer connected to the valve outlet (Fig. 3).

A series of tests were conducted to verify the rotary valve life. For these tests, a test apparatus that simulated sowing operations was used. Schematically, the device was made of a frame able to support a hopper containing soil dust, a support for the test rotary valve, a volumetric dispenser and an electric gear-motor. The gear-motor powered the dispenser and the rotary valve using a chain transmission system. The exhaust dust was conveyed into a container to recover and recycle it (Fig. 4).

To simulate a sowing operation, 1 kg of soil dust was introduced into the hopper. Glass microspheres with a diameter of 90-120 µm were added to the dust (10% microspheres by weight), to increase the dust’s abrasive action in order to accelerate the wear of the valve.

The valve operated at nine revolutions per minute, which corresponded to emptying the cyclone every 16 m assuming a forward speed of the seed drill of 9 km h^{-1}. The test had a time duration of 210 h; this value exceeded the annual usage time normally operated in Italy (150-200 h) (Bertocco et al., 2008; Basso et al., 2011). Leak testing was performed every 30 hours.

3.3. Furrow system efficiency

The efficiency of the furrow system was evaluated in the field by simulating sowing operations using maize seeds without dressing (Fig. 5). Trials were carried out in absence of environmental wind. For these tests, a special test apparatus consisting of two parts (A and B) was used. Part A was comprised of an electrical fan connected to two fan exhaust pipes that flowed air past the furrow system. The electrical fan could produce an air speed of 3 m s^{-1} at the exit of the two pipes. Each pipe had a 100 mm internal diameter. The pipes were placed immediately behind the furrow system and oriented horizontally, 30 mm above the soil surface and separated from one another by 0.50 m. Part B was comprised of two Camfil dust collectors (100 x 200 mm) and support brackets. The Camfil collectors were placed 0.35 m in front of the fan exhaust pipes. The distance between the two collectors was 0.40 m. The forced air entrained the dust particles from the furrow and transported the dust to the Camfil collectors.

For these tests, 30 g of tracer were introduced into the fan of the drill for 10 min (3 g per min) using a volumetric powder feeder (BHT® BD20). Unlike the cyclone dust separation efficiency evaluations, a yellow inert material (Tartrazine E102) was used. Tartrazine E102 has physical characteristics (e.g. particle size, density) similar to the abraded dust from dressed seed (Table 2) (Manzone et al., 2014). Physical characteristics of the Tartrazine

E102 were determined with the same method used for to wheat flour “00”.

The use of two different inert materials was related to the resolution needed in each specific trial. Wheat flour “00” was employed when relatively high amounts of dust were expected in the samplers/collectors (e.g., the Cyclone dust separation efficiency test) and a gravimetric method was used. Alternatively, Tartrazine E102 was used when it was necessary to detect very low amounts of dust in the samplers/collectors (e.g., the furrow efficiency test), where spectrophotometric analysis was used. The contaminated Camfil collectors were washed with 50 ml of deionized water. The washing was analysed with a spectrophotometer (Biochrom Lybra S11) at a wavelength of 434 nm, corresponding to the peak absorption of the dye. The amount of Tartrazine E102 was calculated from the absorbance measured by the spectrophotometer. Each test was made without environmental wind and driving with a forward speed of 6 km h^{-1}. Tests were repeated three times. Between repetitions test collectors were changed without switching the drill’s fan.

3.4. Fan airflow rate and vacuum level inside the seeding element

Tests were conducted with the seed drills in a static position (Balsari et al., 2013). The fan airflow rate was measured at the fan outlet using a 110-mm diameter, 1 m long conveyor where a propeller anemometer (Allemano Testo 400) with 0.1 m s^{-1} precision was positioned.

The vacuum level in the seeding element was measured with a water manometer placed in the hose connecting the seeding element and the fan. The water manometer was made with two vertical tubes each with a 16 mm internal diameter and 2 m tall. The difference in the water level in each tube was determined using a ruler with 1 mm accuracy.

Tests were made using the drill with four and six seeding elements, with and without the kit installed. All measurements were performed adopting a PTO revolution speed of 540 rev min^{-1} and using no dressed seeds. All tests were conducted in similar environmental conditions: 20-25 C° air temperature and 65-70% relative humidity. Each test was repeated three times, and the data were processed using SSPS 2014. The statistical significance of differences between treatments was tested with the Ryan–Einot–Gabriel–Welsch (REGW) test.

4. RESULTS

4.1. Cyclone dust separation efficiency

The data were processed to calculate the cyclone's net dust separation efficiency. When there were no seeds in the hopper, the cyclone removed 99.4% (by mass) of the wheat flour "00". When there were seeds in the hopper, the cyclone removed 99.6% (by mass) of the wheat flour "00" (Table 4). The presence of a value higher than 100 g (the amount introduced in each test) highlights a potential dust deposit inside the cyclone that at the same time falls from the cyclone.

4.2. Vacuum ball rotary valve life

The trials showed that the valve maintained a hermetic seal until 120 h of operation; in fact no pressure losses were registered for the whole period. In contrast, after 120 hours the valve did not guarantee a total hermetic seal: between 150 and 210 h (the assumed

annual operational time for maize drills), the valve lost less than 5 mbar of pressure. In detail, the pressure losses showed an increment never lower than 50% per each successive step of measurement (30 hours). Nevertheless, the maximum pressure loss was only 1% of the input pressure (500 mbar) (Table 5).

4.3. Furrow system efficiency

Spectrophotometric analysis showed no value difference between the deionised water used for device calibration and the deionised water used to Camfil collectors cleaning. This showed that there was no Tartrazine E102 present on the different collectors used in each test. On the basis of this, it is possible to assert that there was no drift effect during the dust insertion into the soil.

4.4. Fan airflow rate and vacuum level in the seeding element

Adding the kit to the standard seed drill configuration did not change the airflow rate exiting from the fan because no statistic significant difference was found between the value recorded before and after kit installation. The airflow rate value depended only on the number of seeding elements present on the seed drill (Fig. 6).

The vacuum levels measured in the seeding element and at the manufacturer's recommended PTO revolution speed (540 rev min^{-1}) were between 62 and 58 mbar. Also in this case, the value show no significant difference. The measured vacuum levels were approximately 30% greater than the optimal value (42 mbar) recommended for maize seeding (Bragatto, 2008) (Fig. 7).

5. DISCUSSION

The tests show that the cyclone system effectively separated 99.4% of the wheat flour "00", even when larger than normal amounts of dust were present. These results agree with previous tests of different cyclone systems (Chapple et al., 2014). Additionally, good results were obtained also by the furrow system which has been able to guarantee the dust insertion into the soil without particles emission in atmosphere.

The valve system tests showed that the valve maintained an essentially hermetic seal. The registered pressure loss (2 mbar) after 150 h of work is acceptable. In normal sowing operation (pneumatic drill with six seeding elements and a forward speed of 9 km h^{-1}), 600 hectares would be seeded in 150 h. The vacuum valve system should be changed every 550 ha, which is equivalent to about three years of farm operation (Bertocco et al., 2008; Basso et al., 2011). Additionally, the valve test was made in severe conditions because abrasive glass spheres were added to the soil dust.

The kit did not negatively impact drill performance. The minimal vacuum losses registered inside of the seeding element (2 mbar) would not impact sowing activities because the resulting pressure still exceeded the value considered sufficient for a correct seeding (42 mbar) (Bragatto et al., 2008).

The kit reduced the contaminated soil area by half and eliminated dust drift because the abraded seed dust was effectively inserted into the soil and it performed better than previously developed and tested systems to reduce dust emission from pneumatic drills. In fact, comparing the results obtained in this study with those achieved in previous

experiments carried out using wheat flour “00” and Tartrazine E 102 and applying the same tests methods on the devices which only convey the air toward the soil (Balsari et al., 2013; Manzone et al., 2014), it was noticed that the tested kit was able to reduce the contaminated area and the dust drift by nearly 100%.

Unlike previous devices, the tested kit could eliminate pesticide contamination on the external surface of the drill. This could eliminate a potential pollution point source and improve operator safety (operators can be contaminated while filling the hoppers and when the drill is being connected to a tractor). The operator health risk may be even higher during maintenance operations (Manzone et al., 2014).

A complete evaluation of the performance of the tested device could be conducted using treated seed (Giffard and Dupont, 2009; Biocca et al., 2011; Tapparo et al., 2012) and under field conditions (Harrington et al., 2004; Friessleben et al., 2010).

Finally, the integrity of drill seals must be determined and appropriate seals used to prevent dust dispersion from the drill’s parts. Dust dispersion can be localized on pipe connections or at the junctions of parts where the air stream is conveyed.

In conclusion, cyclone systems could be a valid solution to clean the exhaust air of maize pneumatic drills. In fact, the tested kit, under conditions used in this experimentation, was able to remove almost 100% of the dust dispersed from the fan of pneumatic drill during sowing activities without affecting the drill’s performance. In contrast to previous devices, this system is also able to insert the particles of dust from dressed seed in the soil avoiding soil surface contamination with pesticides.

On the basis of results obtained in this work, by adopting the tested system it is possible to use dressed seeds and avoid environmental pollution. Furthermore, the kit can be used with all types of maize pneumatic drills (new and already in use) because it is only necessary to direct the air stream from the drill fan into the primary pipe of the kit. In addition, the tested kit could improve operator and environmental safety because the external surface of drill is not contaminated by pesticides. These results apply only to the wheat flour “00” and Tartrazine E 102 used in the tests and will be confirmed in the field using dressed seeds.

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Figures' captions

Fig. 1 - SweepAir® system schematic.

Fig. 2 - Drill used in the trials with the SweepAir® mounted.

Fig. 2 - Devices used to introduce the tracer into the airflow.

Fig. 3 - System used for the hermetic valve tests.

Fig. 4 - Device used for the rotary valve tests.

Fig. 5 - Furrow efficiency test apparatus.

Fig. 6 - Airflow rate measured at fan output with the sowing machine in the standard set up and equipped with the tested kit, using 4 and 6 rows configurations.

Fig. 7 - Vacuum level measured inside the seeding element with the machine in standard configuration and equipped with the tested kit.

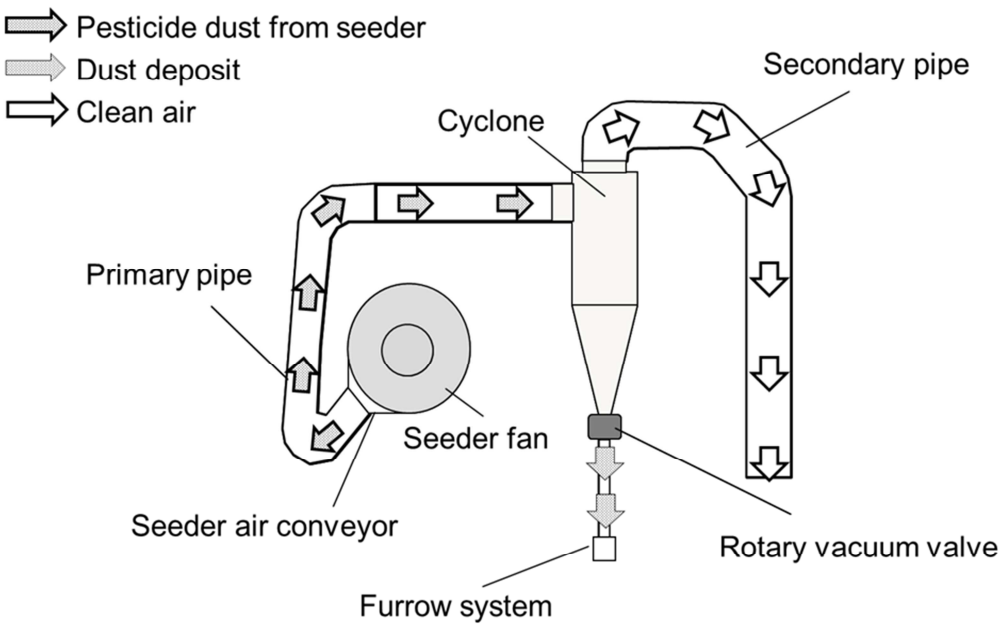

Figure 1

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Figure 2

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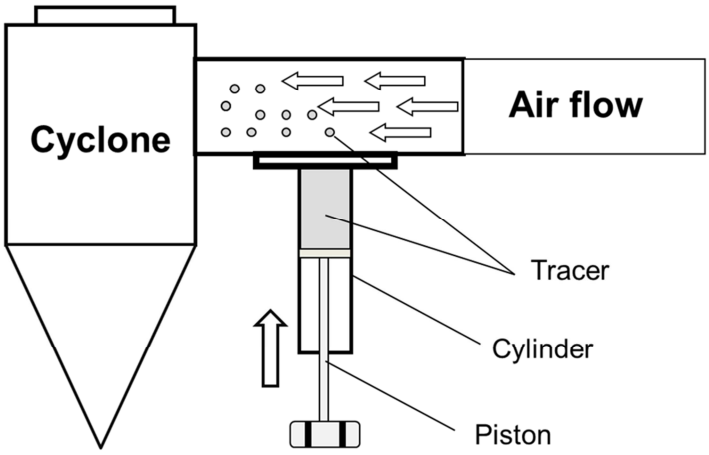

Figure 2

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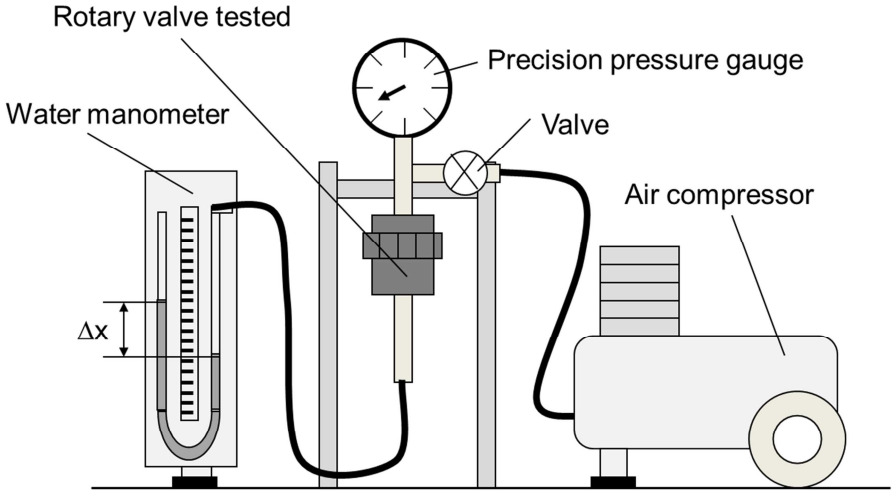

Figure 3

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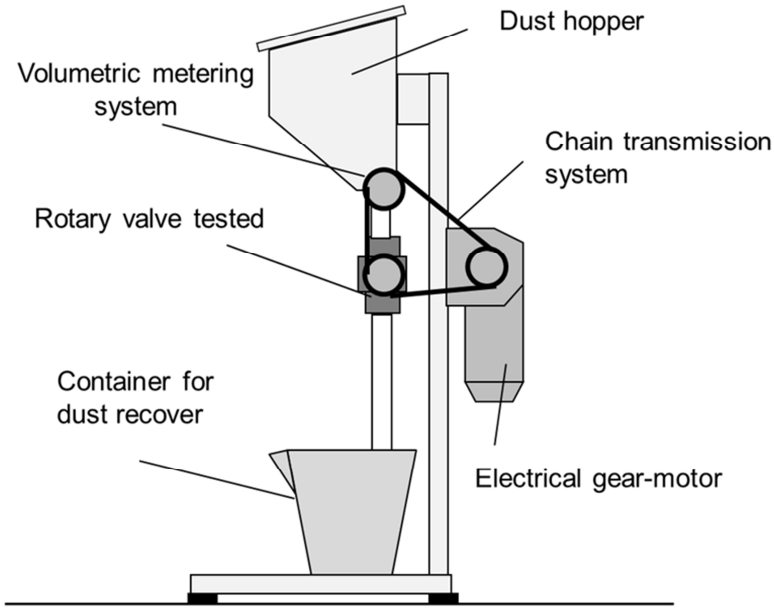

Figure 4

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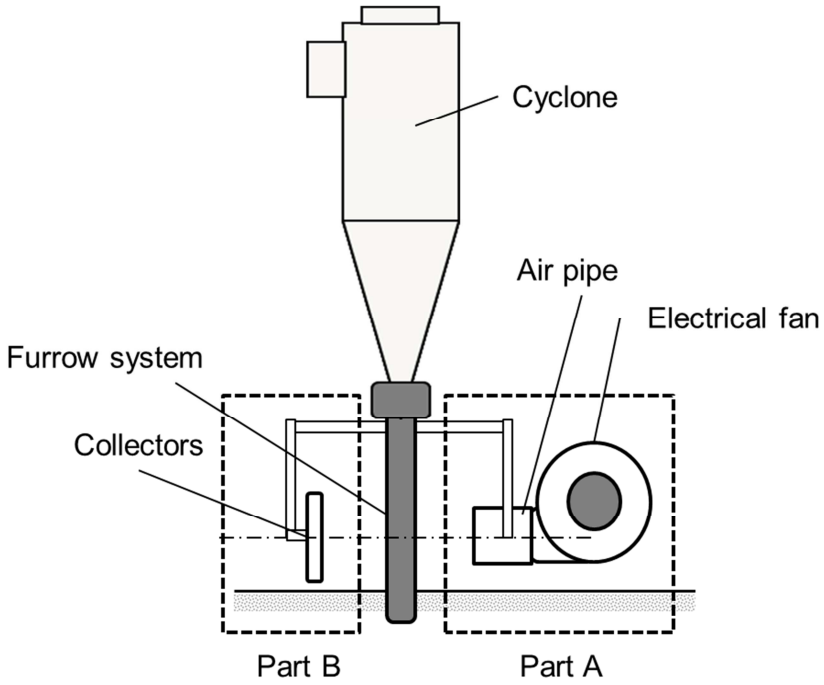

Figure 5

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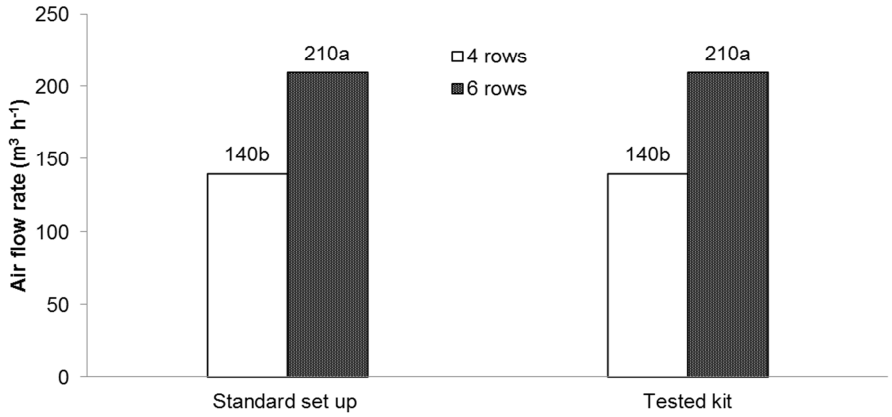

Note: different superscript letters indicate significant differences between treatments for α = 0.05

Figure 6

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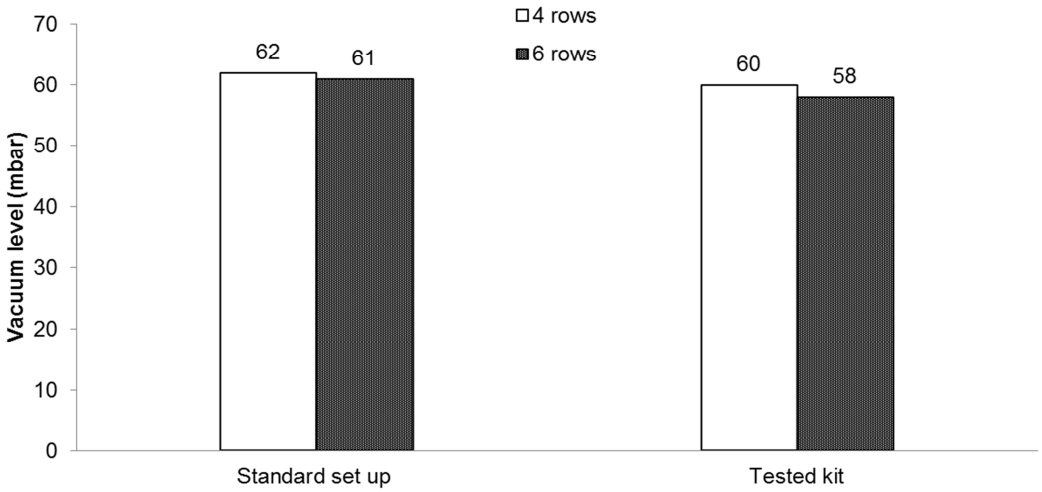

Note: statistical analysis could not detect any significant difference on vacuum level equipping the seed drill with the tested kit

Figure 7

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Tables

Table 1 - Pneumatic drill test configuration.

Manufacturer	Gaspardo®**MARTA**
Seeding elements (n°)	4-6
Fertilizer hoppers (n°)	2
Fan diameter (mm)	410
Fan width (mm)	60
Blades (n°)	10
Blade inclination (°)	31
Blade width (mm)	30
Air outlet size (mm)	230 x 60
Air direction	downwards
Fan rotation speed (rev min^{-1})	5400

Table 2 – Particle sizes of the dust dressed seed, wheat flour “00” and tracer Tartrazine E104.

Size particles	Dust of dressed seed	Wheat flour “00”	Tartrazine E102
D_{10} (µm)	34.1	35.4	42.6
D_{50} (µm)	84.1	74.1	80.1
D_{90} (µm)	180.9	163.5	172.3
Density (g cm^{-3})	0.41	0.45	0.44

Note: No significant difference - Statistical analysis ANOVA unvaried, $p > 0.05$.

Table 3 – ANOVA table

	DF	SS	%	F-Value	P-Value
Diameter	2	85959.42	97.8	639.584	0.001
Dust	2	382.91	0.4	2.849	0.084
Interaction	4	320.28	0.4	1.192	0.348
Residual	18	1209.59	1.4		

Notes: R^2=0.986

Table 4 - Wheat flour “00” collected by cyclone.

Test	mean (g)	min (g)	max (g)	DS	IQR	Efficiency (%)
with seeds	99.6	99.2	100.0	0.4	0.7	99.6
without seeds	99.4	98.8	100.1	0.7	1.1	99.4

Note: SD = Standard Deviation; IQR = Interquartile range
Statistical analysis could not detect any significant difference between test with and without seeds in the hopper

Table 5 - Vacuum ball rotary valve pressure losses.

Hours worked	Pressure losses (mbar)	Increment (%)
0 (new)	0	-
30	0	-
60	0	-
90	0	-
120	0	-
150	2	-
180	3	0.50
210	5	0.67