# Potential external contamination of pneumatic seed drills during sowing of dressed maize seeds



*Published version:*

DOI:10.1002/ps.4148



(Article begins on next page)

# Potential external contamination of pneumatic seed drills during sowing of dressed maize seeds


## Abstract

**BACKGROUND**: The use of pneumatic drills in maize cultivation causes dispersion in the atmosphere of some harmful substances normally used for dressing maize seeds. Some of the dust particles may be deposited on the machine's body, becoming dangerous for the environment and for operators. The aim of the present study was to analyse the amount of dust deposited on the frame of drills during maize sowing operations. Tests were performed with different drills and in different operating conditions.

**RESULTS:** Data analysis showed that a significant amount (up to 30%) of the tracer can be deposited on the drill body. When the wind was not present, higher quantities of tracer were collected and the forward speed did not influence significantly the tracer deposit on the seed drills. The use of different devices that were designed to prevent dust dispersion were able to limit up to 95% but was not able to eliminate the external contamination of the drill.

**CONCLUSION:** The particles present on drills could become a problem for the operator during the filling of the drill. Additionally, the environment can be contaminated if pesticide remains on the drill, generating point source pollution when the drill is parked outside.



**Keywords:** pneumatic drills, maize, dressed seeds, external contamination

## 1. Introduction

The use of pesticides in agriculture has demonstrated many advantages in terms of abundant production and a low-cost food supply,[1] but has caused problems with environmental pollution[2] and human health.[3-4]

The use of pneumatic drills in maize cultivation has helped raise the quality of sowing and ensure higher productivity.[5] On the other hand, it has caused dispersion in the atmosphere of some harmful substances (neonicotinoids) normally used for dressing maize seeds. [6-7]

In recent years, this phenomenon has been the subject of discussion regarding the deaths of bees. These chemicals, when deposited on the crops and on natural vegetation adjacent to maize fields, could be harmful for the bees.[8] In fact, during a sowing operation, the airstream blown out from a pneumatic drill fan - necessary to create a vacuum - can carry a portion of the dust detached from the seeds into the atmosphere.[9]

In recent years, various type of devices have been developed to direct air from the pneumatic drills toward the soil[10-11] or into the furrows used for seed distribution.[12-14] These devices can reduce the dust drift effect by approximately 95% compared to reference equipment,[15-16] but the residual pesticide emitted into the atmosphere is still dangerous for bees.[17]

Some of the dust particles released in the airstream from the fan may also be deposited on the machine's external surface, becoming dangerous for the environment (point source pollution) and for operators, similar to those dangers present when pesticides are applied with sprayers.[18] In fact, potential point source environmental contamination can be observed in the area used to wash the seed drill at the end of the sowing season before its storage or in the outdoor parking area due to rainfall. The operator can be contaminated by the chemical products while filling the seed hoppers and during normal operations, such as when connecting or disconnecting the machine to the tractor.

Moreover, the danger may be even more worrying during the ordinary or unexpected maintenance operations of the seed drill that are sometimes performed by workers (external to the farm) who may be unaware of the external contamination of the pneumatic drill and its toxicity and, therefore, might not wear proper protective clothing or preventively wash the seed drill.

With the aim of increasing knowledge about this topic, ad hoc experimental trials were conducted to quantify the amount of dust deposited on the external surface of three maize pneumatic seed drills in standard and modified configurations.

## 2. Materials and Methods

### *2.1. Seed drills used*

Tests to assess external dust contamination of the machines were made using three pneumatic drills (1 – 2 – 3), representative of Italian drills. All drills showed a similar frame structure and similar design elements, but they differed in the type of air direction outlet fan used (downwards, lateral, or upwards) (Table 1).

Each machine was tested either in its standard configuration or in modified configurations designed to limit the dispersion of dust. A distance of 0.75 m between rows and the application of 75,000 maize seeds per hectare was assumed.[9]

Drill 1 was tested in its standard configuration and in a modified one where the air was conveyed between the wheels of each seeding element. The second seeding machine (drill 2) was tested, in addition to the standard configuration, in two additional configurations aimed at reducing the dust dispersion. One configuration featured the presence of four 100 mm diameter air hoses conveying the air towards the soil, and the second was equipped with one 55 mm diameter air hose for each seeding element, conveying the air close to the seed furrow-share. Drill 3 was tested in its standard configuration and in a modified one where the fan air outlet was conveyed towards the soil by two hoses of 125 mm diameter.

Furthermore, to assess the influence of the fertilizer hopper on the tracer dust deposit on the machine, drill 1 was also tested while equipped with the fertilizer hoppers.

### *2.2. Tests made*

For each drill tested, the amount of dust deposited was determined under three different working conditions to evaluate the influence of two different parameters: wind speed and drill forward speed. Because there was not a specific standard to follow for these tests, the authors carried out the trials according to the ISO 22368-2 set-up for crop protection equipment. This standard was applied because the seed drills, while distributing the pesticide to the soil, was comparable in general terms, to crop protection equipment. The use of Tartrazine E102 as tracer for the simulation of equipment contamination was recommended by this standard. The use of this yellow tracer dust was supported by its physical characteristics, which are similar to those of the dust dispersed by the fans of pneumatic seed drills distributing dressed seeds[10] (Table 2). Furthermore, the use of this tracer also allows testing to be done without specific precautions.

In all tests, the Tartrazine tracer was introduced in the fan air inlet at a rate of 3 g min$^{-1}$ for 10 minutes by means of a volumetric metering system (BHT® BD20).[10] This amount is approximately 300 times greater than the potential amount of abraded dust, when considering a worst case scenario (Heimbach values of <3 g per 100 kg of treated seeds).[19] The external drill contamination was determined with a major dust rate to better highlight eventual differences in values. So that the vacuum systems of the drills could be fully operational, the drills' fans were run for 5 minutes before and after the addition of the tracer. Seeding operations were simulated using untreated maize seed (FAO 500); each seed hopper was loaded with approximately 25,000 seeds, corresponding to the amount present in a commercial package in Italy. All trials were carried out with the seeding elements inserted into the soil.

To evaluate the incidence of wind and forward speed of the seed drills on the external contamination, different tests were carried out. Specifically, the seed drills were tested in a) a static position without wind presence, b) in a static position with wind presence and c) in dynamic trials in the absence of wind.

a) In a static position without wind presence, the sowing operation was simulated in the field by keeping the seed drill at one spot in the field with the seeding elements inserted in a sandy soil at a depth of 60 mm (usually sowing depth). The powering of the machine was provided by the tractor PTO. For the entire test period (20 minutes), the wind velocity, which was measured with a sonic anemometer (Gill Windsonic) at the height of 2 meters, did not exceed 0.5 m $s^{-1}$ (an air velocity lower than 0.5 m $s^{-1}$ has been considered negligible). Instrument accuracy was $\pm$ 0.1 m $s^{-1}$, and the data were acquired at 1 Hz frequency. The air velocity was determined on the basis of arithmetical averages. Tests in which the wind velocity was higher than 0.5 m $s^{-1}$ were considered failures and were not used in data processing. For each machine configuration, the data included the values of three valid tests (3 replications).

b) The trials held in the presence of wind were carried out in a specific wind tunnel maintained by the DISAFA of the University of Turin, where the wind is generated by a fan able to guarantee an even airstream of 3 m $s^{-1}$ velocity, according to the methodology established by Manzone et al.[10] The tunnel, 5 m wide, 3 m high and 50 m long, is made with a modular iron structure covered with nylon film. The airstream is produced by an axial fan of 490 mm diameter equipped with 9 blades inclined at 50°. To guarantee a uniform airstream, the tested drills were always positioned at a distance of 22.5 m from the axial fan outlet in an orthogonal position in comparison to the artificial wind direction (Figure 1).[10]

c) In dynamic trials, the sowing operation was simulated using a forward speed of 6 km $h^{-1}$. The areas chosen for this test had a surface of 0.5 ha (50 m width and 100 m length). Each time the tractor arrived at the headland, it performed turning manoeuvres as in normal practice, without turning off the fan. The soil of this area was a sandy matrix with a moisture content of 4-8% when harrowed before the trials.

At the end of each test, according to the requirements of the ISO 22368-2,[20] seed drills were washed in a catchment pool using deionised water and a spray gun with an adjustable nozzle working at 1 MPa (10 bar) pressure. The spray gun was connected to a pump fed by spray tank with a capacity of 50 litres. After each seed drill was cleaned, the volume of deionised water used was measured by refilling the tank. The tank was refilled using a 2000 $cm^3$ glass pipe with 20 $cm^3$ graduations, corresponding to the accuracy of our measurements. After each test, three representative samples were taken from the collected rinsing liquid. Successively, the catchment pool was accurately and completely cleaned and allowed to dry before the next test.
The amount of tracer deposited on the machine's external surface was determined in the laboratory by spectrophotometric analysis. Samples were analysed with a spectrophotometer (Biochrom Lybra S11) set up at a wavelength of 434 nm, corresponding to the peak of absorption of the dye. The absorbance value read on the instrument enabled the corresponding amount of the tracer to be calculated. The amount of tracer dust deposited on the seed drills was determined as a function of the tracer found in the samples and the amount of water used to clean the seeding machine.

All tests were carried out with an air humidity of 65-75% and an air temperature of 15-20°C. These environmental conditions are very similar to those present during maize sowing in southern Europe.

Every test was performed with 3 replicates for each drill configuration in each working conditions (63 experimental units) (Table 3). Experimental units were randomized using the specific function of Microsoft Excel Software "random number generator". In detail, each experimental unit was identified with a number include between 1 and 63. Then, the randomized number sequence created by Microsoft Excel Software was followed for tests execution. In detail, a completely randomized design (CRD), where the treatments are assigned completely at random so that each experimental unit has the same chance of receiving any one treatment, was adopted in this study.

All data collected were processed with Microsoft Excel Software and analysed with the SSPS 20 (2014) advanced statistics software using GLM model of ANOVA. The statistical significance of the eventual differences between the treatments was tested with the REGW-F test because it has high statistical power with this data distribution.[21] The REGW-F is a multiple step-down procedure used when all simples means are equal. This test is more powerful than Duncan's multiple range test and Student-Newman-Keuls (which are also multiple step-down procedures).

## 3. Results

When the drills were operated in the static position, the highest tracer deposit on the machine frame (30% of the applied amount) was found using drill 1 equipped with fertilizer hoppers, while the lowest value (5% of the tracer applied) was obtained using drill 3 in its standard configuration. When devices for reducing dust drift were mounted on the seed drills, low tracer deposits were generally obtained on the machines' frames (less than 12% of the applied amount). The device used to convey air towards the soil system, which was fixed on drill 1, resulted in the lowest deposit value (7% of the tracer introduced).

Except for drill 3, the kits for the dust drift reduction were guaranteed to reduce tracer deposits on the external seed drill surface by 23% to 38% in comparison to the standard configuration of the machines on which they were mounted (Figure 2).

Similar trends were also obtained in the dynamic trials (Figure 3). In fact, with these trials, the lowest tracer deposit was obtained by drill 3 in its standard configuration, while the highest tracer deposit was registered by drill 1 in the presence of the fertilizer hoppers. Unlike previous tests (those carried out in a static position), the use of kits allowed a limited reduction in the tracer deposited on the frames of the seed drills. This was true especially for drill 2, where the use of the kit facilitated a reduction of only 3% in the tracer deposited (Figure 3).

Operating in the presence of wind, in absolute terms, the tracer deposit on the seed drills is lower for all drill configurations tested in comparison to other tests conducted in the absence of wind. In particular, a reduction of approximately 60% was registered for the kit “conv. Seeding elements”. In this test, the use of the kit on the drills reduced the tracer deposit as much as 71%. Additionally, in these tests, the presence of fertilizer hoppers caused an increase in dust deposit (approximately 70%) (Figure 4).

In general, data analysis showed that a significant amount (up to 30%) of the tracer can be deposited on the drill body. When the wind was not present (tests carried out in the field in static position and in dynamic conditions), higher quantities of tracer were collected and the forward speed did not influence significantly the tracer deposit on the seed drills. In contrast, the presence of the wind can reduce the tracer deposit on the frames of the seed drills (Tables 3 and 4).

The design of the kit intended for dust reduction affected the amount of dust deposits that collected on the drills (Tables 5 and 6).

## 4. Discussion

This experiment demonstrates that maize-sowing operations using coated seeds can result in a significant portion of the dust that is abraded from the seeds being deposited on the frame of the drills either when the drill is in its standard configuration or when equipped with devices designed for dust drift reduction. Nevertheless, devices for dust drift reduction limited the tracer deposit on the frame of the drill (in some situations up to threefold), but were unable to fully eliminate drifting dust. These last results are in line with those obtained in other studies using the same tracer[10] and using the chemical product (seeds treated with neonicotinoids).[15,17,22]

When a seed drill is used in its standard configuration, an important role is played by the direction in which the air exits the fan. In fact, in this experiment, greater tracer deposits on drill frames were obtained with lateral air direction. This result can be caused by the airstream direction in relation to the design of the frame. A recent study noted that when an airstream exits the fan it can be subject to turbulence and generate dust deposits if the stream is intercepted by obstacles.[23]

The relatively better results obtained from the seed drills equipped with a fan with an upwards air exit should not be considered a viable alternative because, in this case, the dust drift is of great magnitude. This latter situation is very dangerous from an environmental pollution point of view because the pesticide dispersed into the atmosphere can contaminate the air,[24] water,[25] and vegetation.[26]

Furthermore, the data processed show that fertilizer hoppers can influence the amount of the tracer deposited on the seed drill frames. This may be attributable to both an increase in the frame surface increment and to the air turbulence created by the presence of the fertilizer hopper.[23]

In this study, the wind may have played an important role because the tests conducted in the presence of the wind showed a significant reduction in dust deposition on the seed drills. This is a good result for “seed drill contamination”, but it is a poor result for environmental pollution. In fact, wind enhances the drift effect of the dust exiting  the drill fan.[14]

A comparison of the results obtained in this work with other studies that measured dust drift for the same drill models and in the same conditions (wind tunnel), a similar trend in terms of deposit reduction (Figure 5) was observed. The drift values reported in the graph are the total deposits collected downwind for a distance of 22.5 metres from the machine. The only exception is the dust drift value that was registered by drill 3; the dust drift effect of this machine was higher because the fan’s outlet directed air upwards.[10,12-13]

The use of different devices enabling dust drift reduction allowed a considerable decrement in the tracer deposits on the machine frame (up to -71%) compared to the original drills’ configurations. Furthermore, for drill 2, the results of the trials showed that each kit for drift reduction provided a different amount of tracer deposit on the frame of the machine. Specifically, the kit that showed the best results in term of drift reduction (Dual Pipe Deflector) also enabled lower machine contamination.[11,27]

Finally, a comparison of the data obtained in this experiment with those obtained by Balsari et al.,[28] who examined sprayer external contamination, highlights a different value. In fact, the amount of tracer deposited (Tartrazine E102) in tests carried out in the same conditions (forward speed of 6 kmh-1 in the absence of wind) showed approximately 95% greater value in comparison to  the drills tested in this work (approximately 15% of the drills tested and 0.5% of the sprayers tested). That difference can be related to the different fan positions (source of pesticide contamination) on the machine. In fact, considering the forward direction of the machines, the fan on the seed drills is mounted in front of the frame, while on the sprayers, it is attached behind the frame. However, this difference may also be attributable to the different form of contaminate materials (liquid and solid) being used.

## 5. Conclusions

This study indicates that the different devices designed for reducing dust dispersion can limit but not eliminate the external contamination of the drills. Dispersed dust could become a serious problem when the driver fills the seed hoppers or couples or decouples the drill machine to a tractor. Furthermore, it could be dangerous when, due to a breakage in the field, the driver performs seed drill repairs without first washing the equipment. The situation would be even more severe if the maintenance of the drill is undertaken by a technician who is unaware of the presence of the chemical products.

Moreover, contaminated seed drills can became a source of environmental pollution when the drills are parked outside and subjected to rainfall. In this case, the rain could wash the dust from the machine body, contaminating the soil under the seed drills.

The solution to this problem lies in the development of better techniques for reducing dust drift. For example, a system that is able to filter the airstream exiting from the seed drill fan by means of air dust separators (sweep-air)[29-30] could minimise dust deposits on the machine frame. Nevertheless, the dust deposited could be reduced as much as 99% by using a modified seed drill in combination with improved seed coat quality.[31]

## References


1. Cooper J, Dobson H, The benefits of pesticides to mankind and the environment. Crop Prot **26**:1337–1348 (2007).

2. Warren N, Allan IJ, Carter JE, House WA, Parker A, Pesticides and other micro-organic contaminants in freshwater sedimentary environments – a review. *Appl Geochem* **18**: 159–194 (2003).

3. Voccia I, Blakley B, Brousseau P, Fournier M, Immunotoxicity of pesticides: a review. *Toxicol Ind Hlth* **15**: 119-132 (1999).

4. Van Maele-Fabry G, Lantin AC, Hoet P, Lison D, Childhood leukaemia and parental occupational exposure to pesticides: a systematic review and meta-analysis. *Cancer Causes Control* **21**, 787–809 (2010).

5. Ivancan S, Sito S, Fabijanic G, Effect of precision drill operating speed on the intra-row seed distribution for parsley. *Biosyst Eng*. **89**: 373-376 (2004).

6. Girolami V, Mazzon L, Squartini A, Mori N, Di Bernardo A, Greatti M, et al., Translocation of neonicotinoid Insecticides From Coated Seeds to Sedling Guttation Drop: A Novel Way Intoxication for Bees. *Journal Econ. Entomol* **102**: 1808-1815 (2009).

7. Greatti M, Barbatini R, Stravisi A, Sabatini AG, Rossi S, Presence of the a.i. imidacloprid on vegetation near corn fields sown with Gaucho dressed seeds. *Bulletin of Insectology* **59**: 99-103 (2006).

8. Nuytttens D, Devareewaere W, Verboven P, Foqué D, Pesticide-laden dust emission and drift from treated seeds during seed drilling: a review. *Pest Management Science* **69**: 564-575 (2013).

9. Schnier HF, Wenig G, Laubert F, Simon V, Schmuck R, Honey bee safety of imidacloprid corn seed treatment. *Bull Insectol* **56**: 73-75 (2003).

10. Manzone M, Balsari P, Marucco P, Tamagnone M, Indoor assessment of dust drift effect from different types of pneumatic seed drills. *Crop Protection*. **57**: 15-19 (2014).

11. Nikolakis A, Chapple A, Friessleben R, Neumann P, Schad T, Schmuck R, et al., An effective risk management approach to prevent bee damage due to the emission of abraded seed treatment particles during sowing of seeds treated with bee toxic insecticides. *Julius-Kuhn-Arch* **423**:132–148 (2009).

12. Biocca M, Conte E, Pulcini P, Marinelli E, Pochi D, Sowing simulation tests of a pneumatic drill equipped with systems aimed at reducing the emission of abrasion dust from maize dressed seed. *Journal and Environmental Science and Health*. Part B. **46**: 438-448 (2011).

13. Balsari P, Manzone M, Marucco P, Tamagnone M, Evaluation of seeds dressing dust dispersion from maize sowing machines. *Crop Protection* **51**:19-23 (2013).

14. Friessleben R, Schad T, Schmuck R, Schnier H, Schoning Rand Nikolakis A, An effective riskmanagement approach to prevent bee damage due to the emission of abraded seed treatment particles during sowing of neonicotinoid treated maize seeds. *Aspects Appl Biol* **99**, 277–282 (2010).

15. Pochi D, Biocca M, Fanigliulo R, Pulcini P, Conte E, Potential exposure of bees, Apis mellifera L., to particulate matter and pesticides derived from seed dressing during maize sowing. *Bull Environ Contam Toxicol* **89:** 354-361 (2012).

16. Herbst A, Rautmann D, Osteroth HJ, Wehmann HJ, Ganzelmeier H, Drift of seed dressing chemicals during the sowing of maize. *Aspects Appl Biol* **99**: 265-269 (2010).

17. Girolami V, Marzaro M, Vivan L, Mazzon L,Giorio C, Marton D, et al., Aerial powdering of bees inside mobile cages and the extent of neonicotinoid cloud surrounding corn drillers. *Iournal of applied entomology* **137**: 35-44 (2012).

18. Balsari P, Marucco P,  The New EU Directives Requirements and the Innovation in Pesticide Application Techniques. *Journal of ASTM International* **8(2)**, Available online at www.astm.org (2011).

19. Heimbach U, Mit Beizen geizen. *Wochenblatt-Mag* **1**: 14–18 (2012).

20. ISO 22368 Crop protection equipment - Test methods for the evaluation of cleaning systems - Part 2: *External cleaning of sprayers*. First edition 2004-03-01.

21. Einot I, Gabriel KR. A study of the Powers of Several Methods of Multiple Comparisons. *Journal of the American Statistical Association* **70**, 351(1975).

22. Tapparo A, Marton D, Giorio C, Zanella A, Solda L, Marzaro M, et al., Assessment of the environmental exposure of honeybees to particulate matter containing neonicotinoid insecticides coming from corn coated seeds. *Environ Sci Technol* **46**, 2592-2599 (2012).

23. Devarrewaere W, Foqué D, Verboven P, Nuyttens D, Nicolai B, Modelling dust distribution from static pneumatic sowing machines. Workshop “International Advances in Pesticide Application” *Aspect of Applied Biology* **122**: 95-101 (2014).

24. Gil Y, Sinfort C, Emission of pesticides to the air during sprayer application: a bibliographic review. *Atmos Environ* **39**, 5183–5193 (2005).

25. Reichenberger S, Bach M, Skitschak A, Frede HG, Mitigation strategies to reduce pesticide inputs into ground- and surface water and their effectiveness: a review. *Sci Total Environ* **384**: 1-35 (2007).

26. De Snoo, GR, Van der Poll RJ, Effect of herbicide drift on adjacent boundary vegetation. *Agric Ecosyst Environ*. **73**:1-6 (1999).

27. Pessina D, Facchinetti D, Reducing the dispersion of seed coating particles containing neonicotinoids inmaize seeding. Proc XVIIth World Congr of International Commission of *Agricultural and Biosystems Engineering*, 13–17 June, Quebec City, Canada, paper CSBE 101280 (2010).

28. Balsari P, Manzone M, Marucco P, Tamagnone M, Evaluation of maize sowing machines performance to establish their potential dissemination of seeds dressing, Workshop “International Advances in pesticide application” *Aspect of applied Biology* **99**:297-304 (2010).

29. Vrbka L, Reinhard F, Neubauer K, Cantoni A, Chapple AC, Bayer AirWasher and SweepAir: technological options for mitigation of dust emissions from vacuum based maize sowing

equipment. Workshop “International Advances in Pesticide Application” *Aspect of Applied Biology* **122**: 113-118 (2014).

30. Manzone M, Marucco P, Tamagnone M, Balsari P, Performance evaluation of a cyclone to clean the air exiting from pneumatic seed drills during maize sowing. *Crop Protection (*in press).

31. Thompson HM, Risk assessment for honey bees and pesticides – recent developments and ‘new issues’. *Pest Manag Sci* **66**: 1157-1162 (2010).

Figure captions

Fig. 1. Placement of equipment in the wind tunnel during the test

Fig. 2. Tracer deposits measured on the frames of seed drills in static position without wind.

Fig. 3. Tracer deposits measured on the frames of seed drills in dynamic trials.

Fig. 4. Tracer deposits measured on the frames of seed drills in static position in the wind tunnel in the presence of an airstream (Tunnel).

Fig. 5. Comparison between the values obtained in another experiment (Manzone et al, 2014) and those obtained in this work.

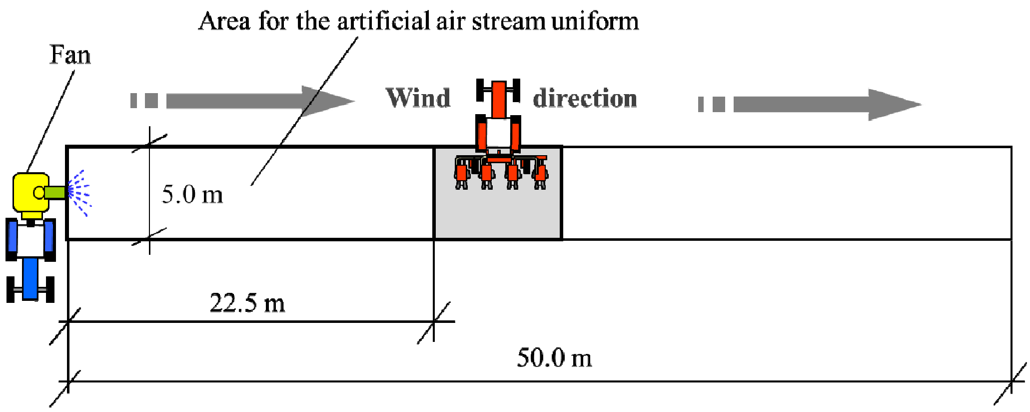



Figure 1

Note for the editor: to be rendered in Black and White

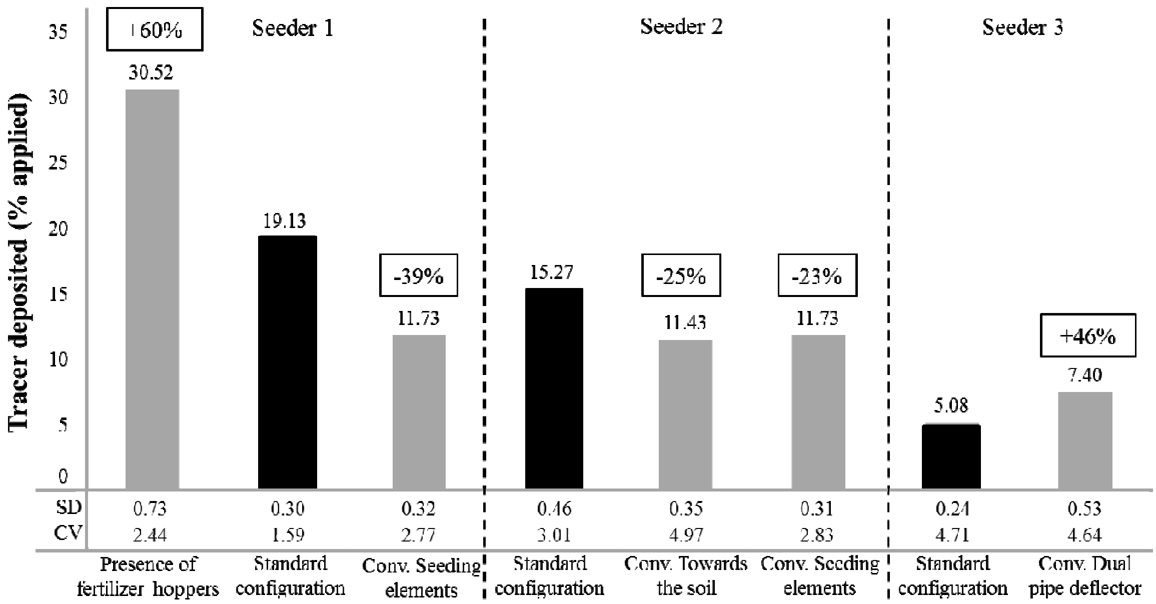

Tracer deposited (% applied)
35
30
25
20
15
10
5
0
Seeder 1
Seeder 2
Seeder 3
+60%
30.52
19.13
-39%
11.73
15.27
-25%
11.43
-23%
11.73
5.08
+46%
7.40
SD
CV
0.73
2.44
0.30
1.59
0.32
2.77
0.46
3.01
0.35
4.97
0.31
2.83
0.24
4.71
0.53
4.64
Presence of fertilizer hoppers
Standard configuration
Conv. Seeding elements
Standard configuration
Conv. Towards the soil
Conv. Seeding elements
Standard configuration
Conv. Dual pipe deflector

Figure 2

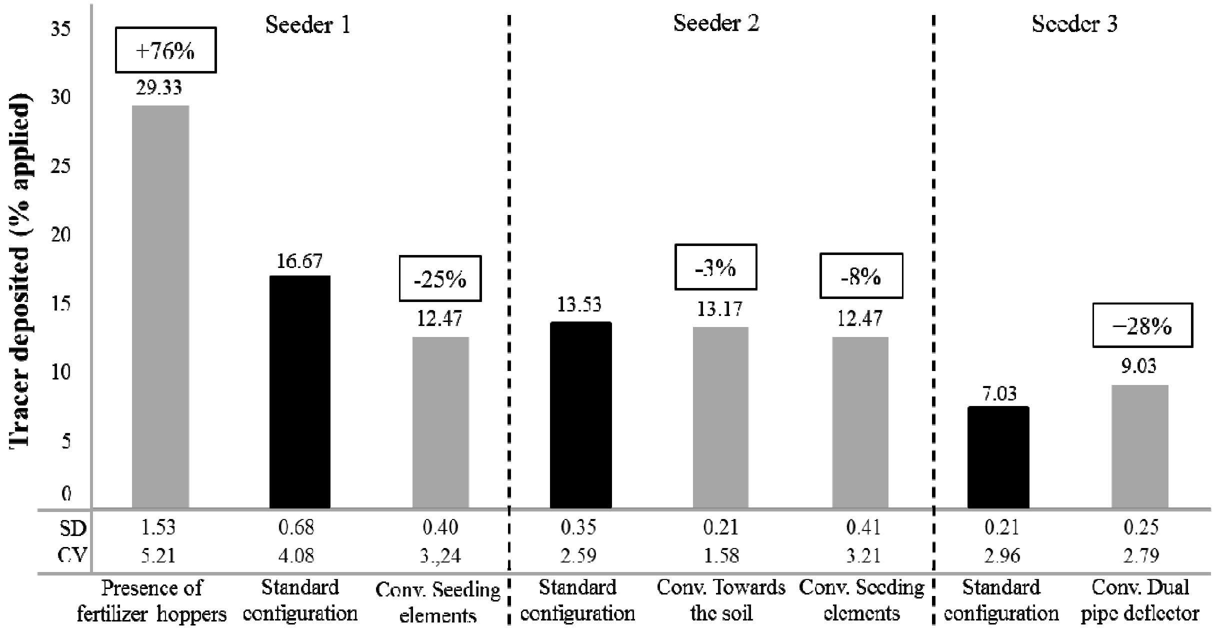

Seeder 1
Seeder 2
Seeder 3
Tracer deposited (% applied)
35
30
25
20
15
10
5
0
+76%
29.33
16.67
-25%
12.47
13.53
-3%
13.17
-8%
12.47
7.03
−28%
9.03
SD 1.53 0.68 0.40 0.35 0.21 0.41 0.21 0.25
CV 5.21 4.08 3.,24 2.59 1.58 3.21 2.96 2.79
Presence of fertilizer hoppers
Standard configuration
Conv. Seeding elements
Standard configuration
Conv. Towards the soil
Conv. Seeding elements
Standard configuration
Conv. Dual pipe deflector

Figure 3

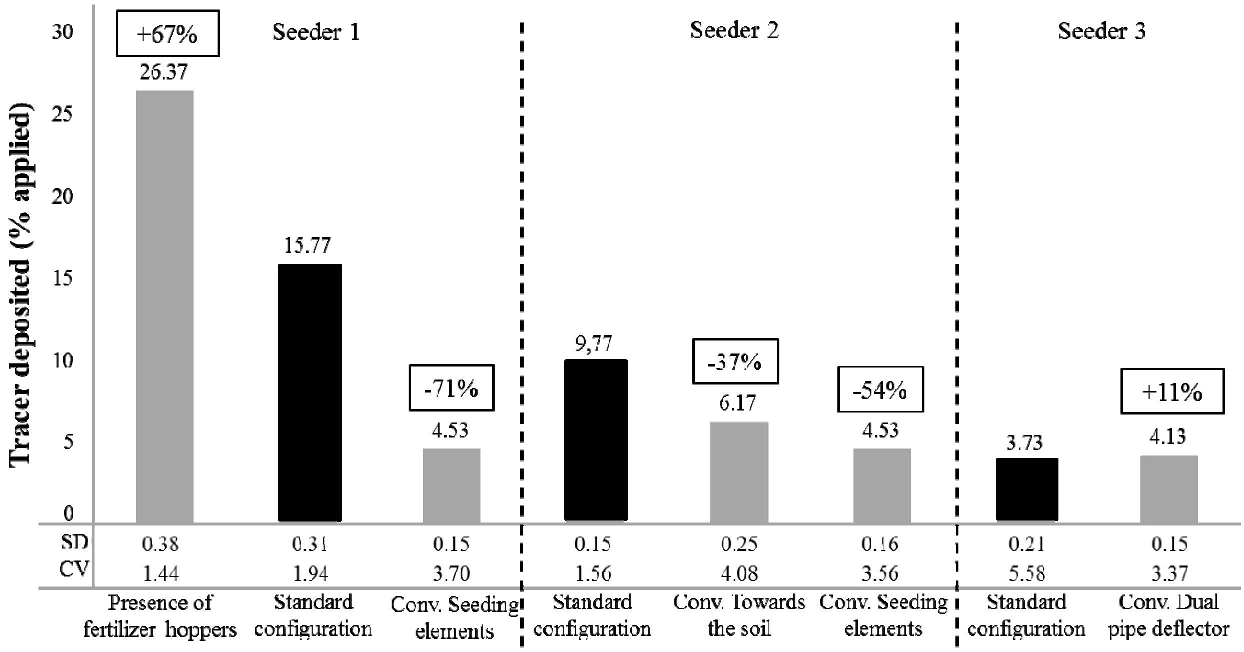
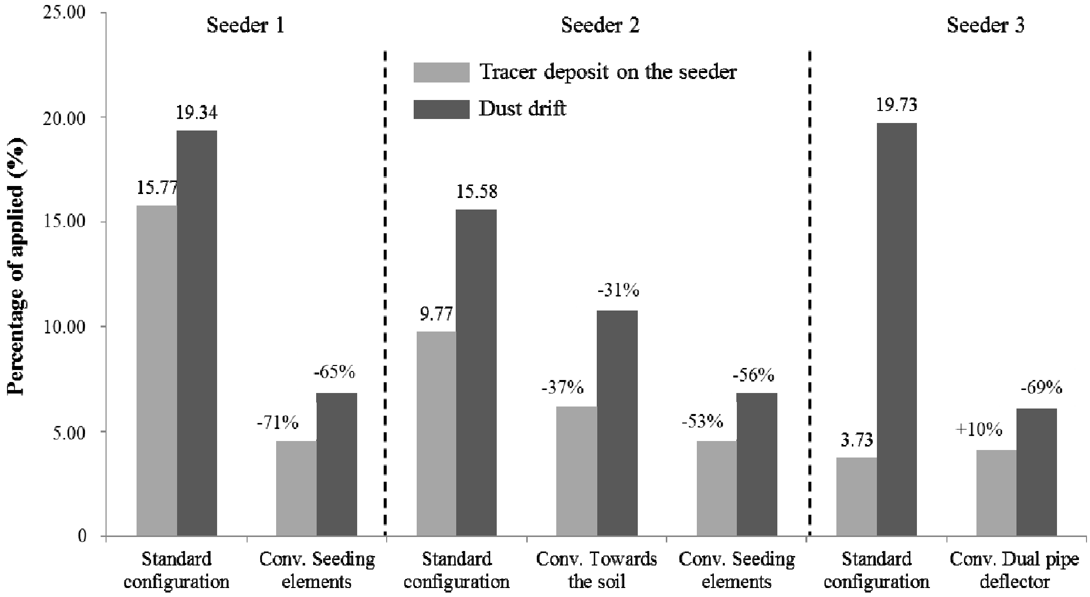

Tracer deposited (% applied)
30
25
20
15
10
5
0
Seeder 1
Seeder 2
Seeder 3
+67%
26.37
15.77
-71%
4.53
9,77
-37%
6.17
-54%
4.53
3.73
+11%
4.13
SD 0.38 0.31 0.15 0.15 0.25 0.16 0.21 0.15
CV 1.44 1.94 3.70 1.56 4.08 3.56 5.58 3.37
Presence of fertilizer hoppers
Standard configuration
Conv. Seeding elements
Standard configuration
Conv. Towards the soil
Conv. Seeding elements
Standard configuration
Conv. Dual pipe deflector

Figure 4



Seeder 1
Seeder 2
Seeder 3
Tracer deposit on the seeder
Dust drift
Percentage of applied (%)
25.00
20.00
15.00
10.00
5.00
0
15.77
19.34
-71%
-65%
9.77
15.58
-37%
-31%
-53%
-56%
3.73
19.73
+10%
-69%
Standard configuration
Conv. Seeding elements
Standard configuration
Conv. Towards the soil
Conv. Seeding elements
Standard configuration
Conv. Dual pipe deflector


Figure 5

Table captions

Table 1. Main technical features of the fans present on the pneumatic drills tested

Table 2. Physical characteristics of the dust from dressed seeds and Tartrazine E102 tracer

~~Table 3. Tests carried out in the experimental trials~~

Table 3. Tracer deposit (% of applied) collected on the machine frames in different tests

Table 4. ANOVA table for dust deposits

Table 5. Dust deposits (% of applied): significant difference between the tests

Table 6. Dust deposits (% of applied): significant difference between the drills and devices tested

| Drills | 1 | 2 | 3 |
|---|---|---|---|
| Seeding elements (n°) | 6 | 6 | 6 |
| Fan diameter (mm) | 440 | 410 | 420 |
| Fan width (mm) | 45 | 60 | 80 |
| Blades (n°) | 10 | 10 | 8 |
| Blade inclination (°) | 30 | 31 | 0 |
| Blade width (mm) | 30 | 30 | 45 |
| Air outlet size (mm) | 105 x 45 | 230 x 60 | 135 x 80 |
| Air direction | lateral | downwards | upwards |
| Fan rotation speed (rev $min^{-1}$) | 5,000 | 5,400 | 4,500 |
| Air velocity (m $s^{-1}$) | 3.2 | 2.2 | 4.4 |
| Air flow rate ($m^3$ $h^{-1}$) | 240 | 210 | 210 |

Table 1

| Size particles | Dressed seed | Tartrazine E102 |
| --- | --- | --- |
| $D_{10}$ (µm) | 34.1 | 42.6 |
| $D_{50}$ (µm) | 84.1 | 80.1 |
| $D_{90}$ (µm) | 180.9 | 172.3 |
| Density (g $cm^{-3}$) | 0.41 | 0.44 |

Table 2

| Machine tested | Working conditions | | |
|---|---|---|---|
| | Static / no wind | Static / with wind | Dynamic / no wind |
| Seeder 1 - Air direction downwards | 3 | 3 | 3 |
| Seeder 1 Mod. (Conv. towards the soil) | 3 | 3 | 3 |
| Seeder 1 Mod. (Conv. Seeding elements) | 3 | 3 | 3 |
| Seeder 2 Mod. (Presence of fertilizer hopper) | 3 | 3 | 3 |
| Seeder 2 - Air direction lateral | 3 | 3 | 3 |
| Seeder 3 Mod. (Conv. Dual pipe deflector) | 3 | 3 | 3 |
| Seeder 3 - Air direction upwards | 3 | 3 | 3 |

Table 3

| | mean | min | max |
|---|---|---|---|
| Static tests | 14.37 | 5.08 | 30.52 |
| Dynamic trials | 14.46 | 7.03 | 29.33 |
| Wind presence (Tunnel) | 10.07 | 3.73 | 26.37 |

Table 3

| | SS | DF | % | F | Sig. | Power |
|---|---|---|---|---|---|---|
| Test | 306.758 | 2 | 8 | 592.185 | < 0.0001 | 1.00 |
| Machines | 3284.183 | 6 | 89 | 2115.578 | < 0.0001 | 1.00 |
| Interaction | 81.301 | 12 | 2 | 26.186 | < 0.0001 | 1.00 |
| Residual | 10.866 | 42 | 1 | | | |

Note: Statistically significant level = 0.05

Table 4

| Ryan-Einot-Gabriel-Welsch | | | |
|---|---|---|---|
| Test type | N | Subset | |
| | | 1 | 2 |
| Tunnel | 21 | 10.07 | |
| Static | 21 | | 14.37 |
| Dynamics | 21 | | 14.46 |
| Sig. | | 1.00 | 0.59 |

Note: Statistically significant level = 0.05

Table 5

Ryan-Einot-Gabriel-Welsch

| Machines | N | Subset | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Presence of fertilizer hoppers (Mod. drill 2) | 9 | 5.277 | | | | | | |
| Air direction lateral (drill 2) | 9 | | 8.522 | | | | | |
| Air direction downwards (drill 1) | 9 | | | 9.466 | | | | |
| Conv. Seeding elements (Mod. drills 1-2) | 9 | | | | 10.255 | | | |
| Conv. Dual pipe deflector (Mod. drill 3) | 9 | | | | | 12.855 | | |
| Conv. Towards the soil (Mod. drill 1) | 9 | | | | | | 17.188 | |
| Air direction upwards (drill 3) | 9 | | | | | | | 28.744 |
| Sig. | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

Note: Statistically significant level = 0.05

Table 6