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17 **Band spreader for the application of slurry solid fractions to orchards**

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23

24 **Abstract**

25 Mechanical separation of pig slurry is widely used in the Piedmont region of northwest Italy, where
26 it is considered a reliable technique to reduce livestock nutrient load on farms. Transport of solid
27 slurry fractions to areas of low animal density, such as where cereals and fruit trees are grown, is
28 considered straightforward. However, because equipment specifically designed to distribute the
29 solid fraction of slurries in orchards was not available a prototype spreader was developed. The
30 machine, with a 4.5m³ volume hopper, included a chain conveyor metering device and
31 hydraulically-driven spinning plate so that the working width can be adapted to tree row space and
32 shape differences enabling its use in a variety of operating conditions and orchard types. To ensure
33 application of solid fraction was in compliance with crop requirements and regulations, the spreader
34 was equipped with an electronic rate control system enabling target nutrient rates ranging from 10
35 and 120 kg [N] ha⁻¹. It was tested for longitudinal and transverse distribution at different application
36 rates and forward speeds. Test results showed that the control system maintained suitably even
37 distribution patterns and steady application rates regardless of forward speed.

38

39 Keywords: automatic rate control, orchards organic fertilisation, manure band application.

40 **Nomenclature**

N Nitrogen

SRF	Short rotation forestry
GPS	Global positioning system
TN	total nitrogen
q	manure flow rate, kg min^{-1}
Q	target nutrient application rate, $\text{kg [nutrient] ha}^{-1}$
W	working width, m
F	forward speed, km h^{-1}
T_n	target nutrient content in manure, kg Mg^{-1}
TS	total solids
CV	coefficient of variation
cv	cultivar

41

42 **1. Introduction**

43 In livestock farming systems, animal manure generally plays a positive role by acting as a source of
 44 nutrients and organic matter to maintain soil productivity. However, several areas in Europe suffer
 45 from a problematic nitrogen (N) surplus where the difference between N soil inputs and soil
 46 removal by the crops is too high. This often occurs where there is a concentration of livestock
 47 farms. The over-application of N to crops or grasses in the form of manure can result in nitrate
 48 leaching to ground water or high N levels in surface waters leading to eutrophication and low
 49 dissolved oxygen levels (Durand et al., 2011). To prevent such adverse effects, European Union
 50 Nitrate Directive (91/676/EC) mandated that the animal manure N application rates in “nitrate
 51 vulnerable zones” should not exceed $170 \text{ kg [N] ha}^{-1} \text{ year}^{-1}$.

52 Furthermore, farmers in these areas were asked to find additional lands for disposal of the N
 53 surplus; a difficult task in areas where raising livestock is widespread and animal loading is high.
 54 This issue is relevant in Italy as more than 70 % of its livestock production is concentrated in the

55 western Po Valley (Capri et al., 2009) in the regions of Piemonte, Lombardia, Emilia Romagna, and
56 Veneto (ISTAT, 2012). Consequently, mechanical slurry separation has been recognised as being
57 important and used as a reliable technique to reduce farm N loadings. The nutrients content in the
58 solid fraction can be economically transported from high intensity animal farming areas to adjacent
59 areas with lower animal densities. In the Piemonte region of northern Italy, orchards, vineyards, and
60 short rotation forestry (SRF) areas are often only a few kilometres away from areas characterised by
61 high livestock densities. In Cuneo province for instance, 63,000 ha of orchards are available,
62 representing 20 % of cropped land (ISTAT, 2012). Orchards, as well as vineyards, are currently
63 managed using chemical fertilisers and characterised by a lack of soil organic matter content
64 (Cerutti et al., 2011). Historically, humified farmyard manure was used in orchards, but it has
65 become quite difficult to obtain. The transfer of solid fraction to orchards could, therefore, represent
66 an opportunity to utilise local nutrient surpluses.

67 An impediment to the widespread adoption of applying separated slurry solid fraction in orchards is
68 the attitude of the farmers who are not in favour of its use mainly due to the lack of appropriate
69 specific methods of application. Conventional machines, such as spreader for farmyard manure or
70 chemical fertilise, are occasionally used, but they are rarely good options because the slurry solid
71 fraction characteristics (e.g., heterogeneous particles sizes) affect spreading uniformity and cause
72 the metering device to clog. Moreover, separated solid slurry applied in orchards requires
73 equipment to be adaptable to fit different row spacings (from 3 m in SRF to 5 or 6 m in hazel
74 groves) and for application to the areas of optimal plant nutrient uptake. The ability to accurately
75 apply the target application rate is also crucial for orchard crops since their nutrient requirements
76 are lower than for open field crops; for example it is 80-100 kg [N] ha⁻¹ year⁻¹ for peach orchards.

77 To cope with these requirements and operational limits, a prototype spreader for solid fraction band
78 application in orchards was designed, constructed and tested. Tests were carried out to assess
79 spreader performance in several areas: i) distribution evenness, ii) application rate accuracy, and iii)

80 working capacity.

81

82 **2. Materials and methods**

83 2.1. Definition of the application surface

84 Prior to the development of the separated solids spreader, a study was carried out to define the
85 typical orchard row spacing application area. To optimize tree fertilisation it is necessary to apply
86 the solid fraction at the correct rate and where roots are able to take up nutrients. The proper
87 separated fraction application rate depends on the orchard cultivar and age. In the peach orchards
88 across the western Po Valley, the application rates ranged from 50 and 120 kg [N] ha⁻¹year⁻¹ (PSR,
89 2006). To obtain maximum organic fertilisation efficiency, the material must be applied in early
90 spring. Baldini (1986) and Baldoni et al. (1992) prescribed the optimal separated solids application
91 area in orchards as being in a band approximately 1.0 m wide and 0.5 m from the tree row while
92 avoiding direct contact with the trees in order to limit the risk of plant disease development. This
93 latter consideration dictated that the separated solids spreader be designed so as to enable
94 distribution in a 1.0 m wide band beside the machine and 0.5 m from tree rows (Fig. 1). A metering
95 device able to accommodate the rates described above was developed as shown in Fig. 2.

96

97 2.2. Prototype solid fraction spreader

98 A band application separated fraction spreader was designed and constructed consistent with
99 maintaining working autonomy and operating within the characteristically narrow row spacings (3.0
100 – 5.0 m) found in orchards and SRFs northwest Italy. The constructed spreader included the
101 following components:

102 - square tube steel frame;

103 - 4.5 m³ hopper;

- 104 - non-steering axle fitted with wide section and low pressure tyres (500/60 -22.5) to reduce soil
- 105 compaction and sward damage;
- 106 - band spreading device consisting of two hydraulic-powered spinning plates, one per side,
- 107 mounted on a hydraulic-powered frame for the proper placement of the separate solids (0.5 m
- 108 from tree row in a 1.0 m wide band);
- 109 - automatic rate controller;
- 110 - global positioning system (GPS) receiver.

111
112 The hopper, with a volume of 4.5m³, was constructed using wooden plank lateral walls supported
113 by steel profiles. The rear steel wall of the hopper is lowered during loading operations and during
114 transport to avoid accidental material spillage. It was raised during the distribution phase to let the
115 solid material flow toward the distribution system using the chain conveyor mounted on the steel
116 floor. The automatic rate controller was designed to apply manure nutrients at target application
117 rates ranging from 10 and 120 kg [N] ha⁻¹. This range was chosen to address the nutrient application
118 needs of the most common orchards in the western Po Valley, and while considering nutrient
119 content ranges (e.g., total nitrogen [TN] = 4-8 kg Mg⁻¹) (Dinuccio et al., 2014) in the various types
120 of livestock slurry solid fractions produced in this area.

121 The automatic rate controller includes several components:

- 122 - proximity sensor mounted on the right wheel rim for spreader forward speed determination;
- 123 - moving floor comprised of a chain conveyor driven by a hydraulic motor;
- 124 - rotation speed sensor for control of the sprocket-wheel and chain conveyor speed;
- 125 - electronic unit (DIKEY-John[®] IntelliAg AI50, DICKEY-John Corporation, Auburn, IL, USA)
- 126 to control operational parameters;
- 127 - a GPS receiver for manure application traceability.

128 The on-board computer had a clear, simple, and logical operation and large low-reflection display.
129 Its small size required little tractor cab space. To apply the desired rate (kg [target nutrient] ha⁻¹),

130 the operator needed to sample the separated slurry fraction and have it its nutrient content analysed
131 in a laboratory. The obtained value (in kg Mg⁻¹ of manure), the target application rate (in kg
132 [nutrient] ha⁻¹), and the working width were then entered on the control panel (Fig. 2).

133
134 The on-board computer calculated the application rate using Eq. (1):

$$135 \quad q = \frac{Q \cdot W \cdot F}{0.6 \cdot T_n} \quad (1)$$

136 Where

137 q is manure flow rate (kg min⁻¹),

138 Q is target nutrient application rate (kg [nutrient] ha⁻¹),

139 W is working width (m),

140 F is forward speed (km h⁻¹) and

141 T_n is target nutrient content in manure (kg Mg⁻¹).

142 Specific capacity (kg rev⁻¹) of the conveyor sprocket was found by a preliminary test to depend on
143 chain conveyor velocity, hopper rear wall height over the moving floor, and product characteristics.

144 To ensure manure nutrients are applied at the desired rates, the metering device had to be calibrated
145 whenever a new source of manure with different characteristics (e.g., moisture content) was used.

146 The automatic controller adjusted the product application rate to the travel speed and working width
147 of the spreader. The system checked if the applied application rate matched the target value by
148 determining the rotating speed of the chain conveyor sprocket, and if necessary, altering its speed.

149 The spreading system consisted of two hydraulically-driven belt conveyors and two hydraulically-
150 driven spinning plates positioned on both sides of the machine. The pulleys of the belt conveyor
151 counter-rotate (the left runs counter clockwise and the right runs clockwise) when the material was
152 being spread on both sides of the machine. The plates rotated clockwise (or counter clockwise)
153 when the material was applied on one side only (i.e. left or right, respectively).

154 The chain conveyor pushed the solid fraction through the opening in the rear wall of the hopper that

155 was held 0.1 m above the moving floor during spreading in order to deliver a constant flow of solid
156 fraction onto the belt conveyors. The product is then carried to the spinning plate and spread onto
157 the soil.

158 The spinning plates were mounted on a frame that could be adjusted 0.5 m from the sides of the
159 machine, allowing for working width to be adjusted from 3.9 to 6.0 m. Both rotation speed and
160 spinning plate inclination were adjustable for the spreading ranges found in different orchard row
161 spacings (Fig. 3).

162 2.3. Functional trials

163 Machine performance was tested for transverse and longitudinal distribution evenness (European
164 Standard EN 13080 indications) and accuracy of the automatic rate controller. All tests used pig
165 slurry separated solid fraction obtained by a screw-press (Chior[®] model 300, Chior Meccanica SRL,
166 Campitello di Marcaria, Mantova, Italy) installed at a “farrow to finish” farm in Cuneo Province.
167 Pig slurry solid fraction produced by a screw press was used, since mechanical slurry separation by
168 screw press is commonly performed on pig farms in the Piemonte region. Specifically, the trial
169 solid fraction had a 24% total solids (TS) content, a 3kg Mg⁻¹ TN content, and a density of 650 kg
170 m⁻³.

171

172 2.3.1. Longitudinal distribution evenness

173 The separated fraction flow of the test unit was calculated from measurements of changes in mass
174 and elapsed time from start to the point when the flow dropped by 5.0 kg s⁻¹. A portable single axle
175 weighbridge scale (Sinergica[®] model WWSD10T, Sinergica Soluzioni S.r.l., Montesilvano, Pesaro,
176 Italy) was employed for this purpose. The rate controller was set to apply 50 and 25 kg [N] ha⁻¹ to a
177 4.0 m width at 5.0 km h⁻¹ forward speed, and the scale control device was set to record the weight
178 every 5 s during hopper emptying. The tests took place on a separated solid platform near an above-

179 ground storage tank.

180

181 2.3.2. Automatic rate controller accuracy

182 A series of tests was conducted to assess precision and response time of the automatic rate
183 controller with variations in spreader forward speed. The tests were performed by adding a
184 proximity sensor to the spreader wheel on a hydraulic-driven roller device to allow simulation of
185 different forward speeds (1.0 - 10.0 km h⁻¹). A data logger recorded the signals from the wheel
186 proximity sensor and from the speed sensor mounted on the chain conveyor sprocket shaft. The
187 central unit was set to three different application rates (20, 40, and 60 kg [N] ha⁻¹); forward speed
188 was continuously changed by an average value of 3.5 km h⁻¹. In a second set of tests, machine
189 forward speed was continuously altered by an average value of 5 km h⁻¹ with an application rate of
190 60 kg [N] ha⁻¹. The response of the chain conveyor sprocket to forward speed changes was
191 continuously recorded in all tests.

192

193 2.3.3. Transverse distribution evenness

194 Tests were carried out on a horizontal surface with negligible wind velocity and the forward speed
195 was set to 5.0 km h⁻¹ (EN 13080, 2002). To measure transverse distribution evenness, 0.5 x 0.5 x
196 0.1 m collection containers were placed to the right of the spreader (when viewed in the direction
197 travel), with their edges parallel to the ground surface and perpendicular to the line of travel of the
198 machine, along its total spreading width. The spinning plate was maintained in a horizontal position
199 and operated at 330 rpm. The amount of solid fraction collected in each container was weighed
200 using an electronic scale (Kern ECB 50K50, KERN & Sohn GmbH, Balingen, Baden-
201 Wuürttemberg, Germany; capacity 50 kg, accuracy 0.05 kg). The data were then processed
202 according to EN 13080 (2002) to obtain the distribution pattern of the machine and the coefficient
203 of variation (CV).

204

205 A test was also performed to assess the potential range of band width with adjustment of the
206 spinning plate incline and rotation speed (Fig. 4). Three rotating speeds (250, 330, and 400 rpm)
207 and two inclinations of the plate (0 and 30°) were compared.

208

209 2.3.4. Separated solids spreader productivity

210 Machine capacity is used to predict equipment performance in a farm system, which determines
211 operating efficiency. If a series of operations contain an activity that is a “system bottleneck,” the
212 capacity of the entire system will be reduced due to the prolonged time for a single step (Bochtis &
213 Sørensen, 2010). Most farmers consider capacity (ha h^{-1}) as a quick way to evaluate the ability of a
214 machine to complete a task in a timely fashion. However, on most farms, other associated
215 operations must be completed during manure spreading (Grisso et al., 2008). For example, during
216 manure spreading operators must refill the spreader hopper as it empties and transport the manure
217 from storage to the field.

218 Fertilisation tests were performed with the prototype in a peach orchard (cv Spring bright, orchard
219 design 1.80 x 3.90). The solid fraction was applied during the second half of April to a plot of 5500
220 m^2 . During the trials, two N application rates (25 and 50 kg [N] ha^{-1}), forward speeds from 5.5 to
221 6.5 km h^{-1} , and a working width of 3.9 m were tested. To verify the ability of the spreader to
222 maintain the required application rate, the spreader was weighed before and after the two
223 distributions on a portable, single axle weighbridge scale (Sinergica[®] model WWSD10T, Sinergica
224 Soluzioni S.r.l., Montesilvano, Pesaro, Italy) with a 10,000 kg capacity and $\pm 1.0 \text{ kg}$ accuracy.
225 During manure application, the following working times were recorded following ASABE (2010)
226 Standard indications:

227 - theoretical field time (effective manure distribution time);

228 - in-field displacement time (machine time in the field with metering and distribution systems off,
229 such as travel in the field and turning time)

- 230 - travel time (travel to and from field, farmstead movement to reach the separated solids platform);
231 - loading time (time required to fill hopper);
232 - time to repair, maintain, and set machine.

233 These factors were used to determine theoretical field product capacity and machine field
234 efficiency. Recorded data led to development of a worksheet to value the effect of different
235 operating conditions on machine efficiency, alternative transport options, and suitable distribution
236 chains for pig slurry separated solids distribution in orchards. Spreader productivity was measured
237 under the following conditions: machine forward speed of 6.2 km h⁻¹, manure spread at a working
238 width of 3.9 m, and average transport distance of 1450 m. In this scenario, N was applied at 25.0 kg
239 ha⁻¹ and 50.0 kg ha⁻¹.

240

241 3. Results and Discussion

242 3.1. Longitudinal distribution evenness

243 The flow of separated fraction during hopper unloading in conditions of 50 kg [N] ha⁻¹ and 25 kg
244 [N] ha⁻¹ averaged 8.7 kg s⁻¹ and 4.6 kg s⁻¹, respectively. A steady product flow produces good
245 longitudinal distribution and is fundamental to proper application rate control (Hansen, 2004). For
246 each longitudinal distribution test, the stretch within the tolerance zone was determined as the sum
247 (in %) of the sub-stretches during which momentary flows lay within ± 15% (EN 13080, 2002).
248 Results were 69.7% at 50 kg[N] ha⁻¹ and 71.3% at 25 kg[N] ha⁻¹ of unloading time (Fig. 7).

249

250 One of the main problems in longitudinal evenness is the management of the distribution tail, that
251 is, as the hopper becomes empty, product flow falls below the tolerance zone (15% of the steady
252 flow limit). However, under our test conditions, the shape of the overlapped longitudinal
253 distribution diagram indicated that good longitudinal evenness (CV below 15%, data not shown)
254 was attained.

255

256 3.2. Automatic rate controller accuracy

257 The tests showed that the controller read the output signals well from the various sensors and that
258 the control devices sufficiently managed (solenoid valves that control the hydraulic system) the
259 engine that moved the sprocket of the chain conveyor.

260 The automatic rate controller demonstrated its ability to rapidly adjust the rotation speed of the
261 sprocket following variations in machine forward speed. The system adjusted the hydraulic pump
262 rotational speed in < 2 s (Fig. 6).

263 The rate control system enabled the operator to apply the desired amount of TN, regardless of
264 spreader forward speed. Errors between programmed and measured N application rates ranged
265 between 1 and 10 %. With a working width of 4 m and a N content of separated solids of 3 kg m^{-3} ,
266 the machine applied nitrogen at a rate of $40.0 \pm 0.4 \text{ kg [N] ha}^{-1}$ despite two significant forward
267 speed changes that required about 10 s each to return to the specified application rate (Fig. 7).
268 Similar good responses to speed variations were also obtained with application rates of 20 and 60
269 kg [N] ha^{-1} .

270

271 3.3. Transverse distribution evenness

272 Tests performed to assess the transverse distribution pattern according to the incline and rotation
273 speed of the spinning disk resulted in a CV from 8.5 % to 28.8 % (Fig. 8), which complied with EN
274 Standard 13080 (2002) requirements (i.e., $\text{CV} < 30$ %) for good uniformity of manure spreading.
275 The 30° rearwards inclination at 330 rpm spread most of the product across 1.0 m wide area, which
276 is considered as meeting the requirement to apply the solid fraction to the area where plant nutrient
277 uptake occurs. This setting also gave higher uniformity (Fig. 8).

278

279 3.4. Separated solids spreader productivity

280 For the scenario where N was applied at 25.0 kg ha⁻¹ (8.3 Mg ha⁻¹ material with 3 kg [N] Mg⁻¹
281 content), the machine recorded a product capacity of 6.8 Mg h⁻¹ and a field capacity of 0.8 ha h⁻¹
282 (32.8 % field efficiency) (Fig. 9). At an application rate of 50 kg [N] ha⁻¹ (16.6 Mg ha⁻¹), the
283 machine recorded a product capacity of 8.1 Mg h⁻¹ and a field capacity of 0.5 ha h⁻¹, which gave a
284 field efficiency of 19.5 %.

285

286 The low values of field efficiency were primarily due to the high incidence of travel time to and
287 from the field and secondly the incidence of in-field movements (to arrive at the distribution
288 starting point and to arrive at the field hedge following hopper emptying). Field efficiency can be
289 improved by optimising spreader in-field runs and avoiding hopper emptying in the forward path
290 and/or filling it in-field. Taking the scenarios described above, and assuming a forward operating
291 speed of 6.2 km h⁻¹, and a working width spread of 3.9 m, calculations demonstrated how it was
292 possible to increase field efficiency to 62.3 % and 46.5 % at application rates of 25.0 kg [N] ha⁻¹ and
293 50.0 kg [N] ha⁻¹, respectively. These values correspond to field capacities of 1.5 and 1.2 ha h⁻¹ and
294 to product capacities of 12.9 and 19.2 Mg h⁻¹ (Fig. 10).

295

296 In-field loading of the spreader hopper required that a product heap be formed at the edge of the
297 field. To avoid nitrogen loss of nitrogen in the form of ammonia emissions and nutrient leaching
298 during storage (Petersen & Sørensen, 2008), it is preferable to transport the material immediately
299 before spreading. In this case, the transport chain, from the separated solids platform to the field,
300 must achieve a product capacity equal to, or above that, of the spreader. Thus, if separated solids are
301 distributed at 16.6 Mg ha⁻¹, then the transport chain must operate with a minimum product capacity
302 of 19.2 Mg h⁻¹. Therefore, if a three-axle trailer of 15 Mg (i.e. maximum legal gross weight 20 Mg)
303 is used and unloaded closed to the field hedge, the transport distance has to be no greater than 8.5
304 km. If a 16 Mg dumper were mounted on the three-axle truck (i.e. maximum legal gross weight 25
305 Mg), it would be possible to operate with a transport distance of 19.0 km.

306
307

4. Conclusions

308 The prototype spreader appeared to be a reliable machine for swine slurry separated solids
309 application in orchards when nutrients are applied at the proper amounts and uniformity with a
310 well-performing automatic rate controller. Specifically, under the test conditions, the spreader
311 application rate uniformity performance satisfied the EN 13080 standard requirements for efficient
312 manure field handling. Since manure characteristics may affect machine performance, confirmatory
313 trials should be performed using different doses and manure types (e.g., cattle slurry solid fraction,
314 digested slurry solid fraction).

315 The spreader accommodates a wide range of settings that enables the operator to fit different row
316 spacing and operating conditions, such as solid fraction application in narrowly spaced orchard
317 rows. By setting the rotation speed and spinning plate incline, manure can be applied correctly to
318 meet row spacing and plant dimensional needs. To achieve the best field capacity results required
319 that the spreader hopper be loaded close to the field hedge. In addition, this technique needs to be
320 paired with the proper transport chain that dictates more investment and higher running costs,
321 supportable only by large farms or contractors. Until now, the GPS system has only been tasked
322 with manure N application traceability, but it could be integrated into a solid fraction precision
323 application system.

324

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330

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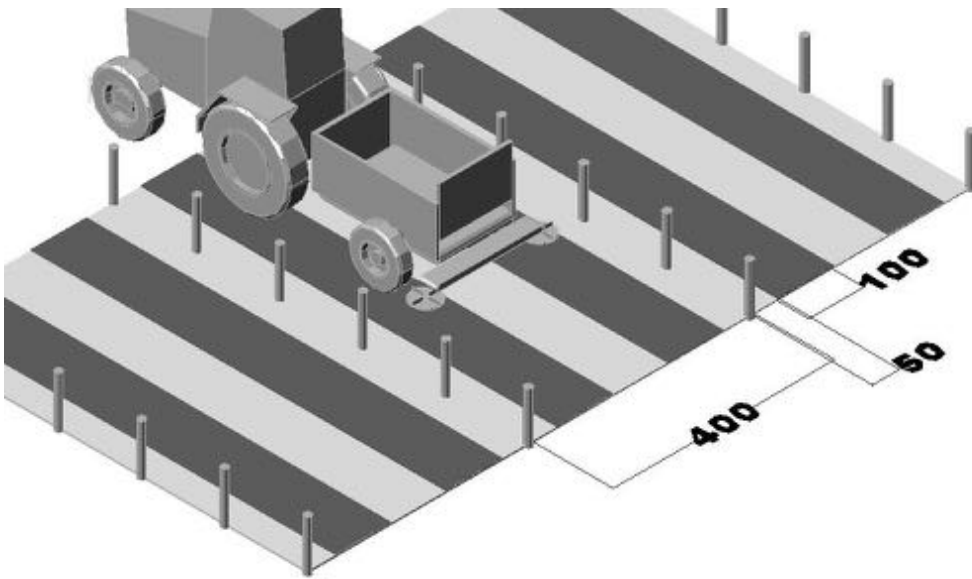
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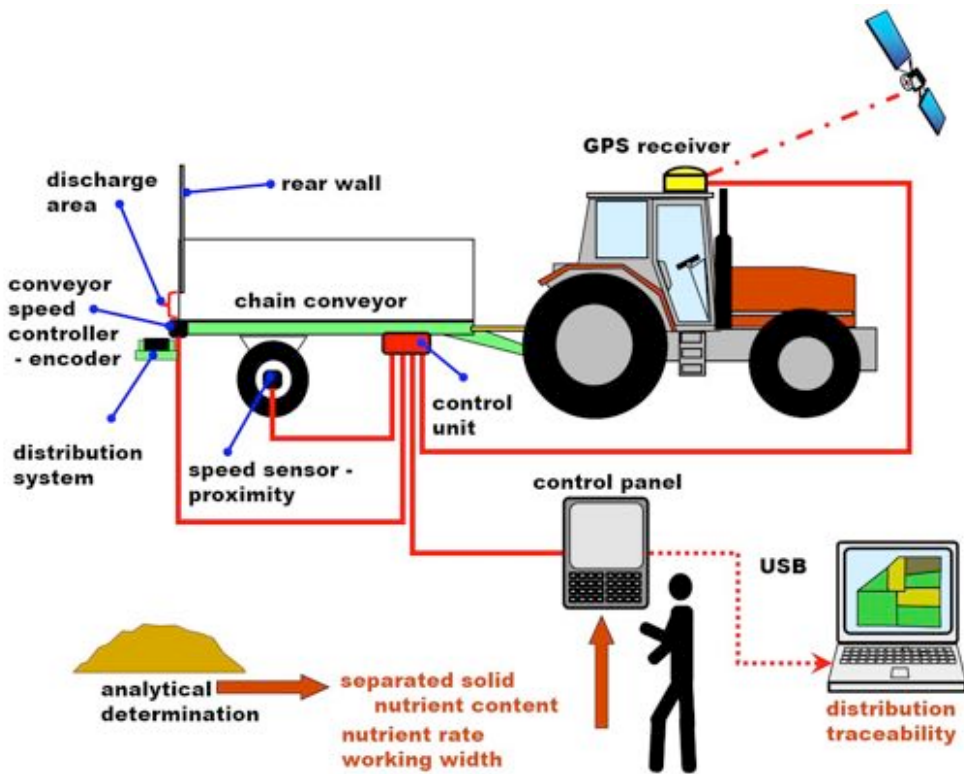


373

374 Fig. 1.

375

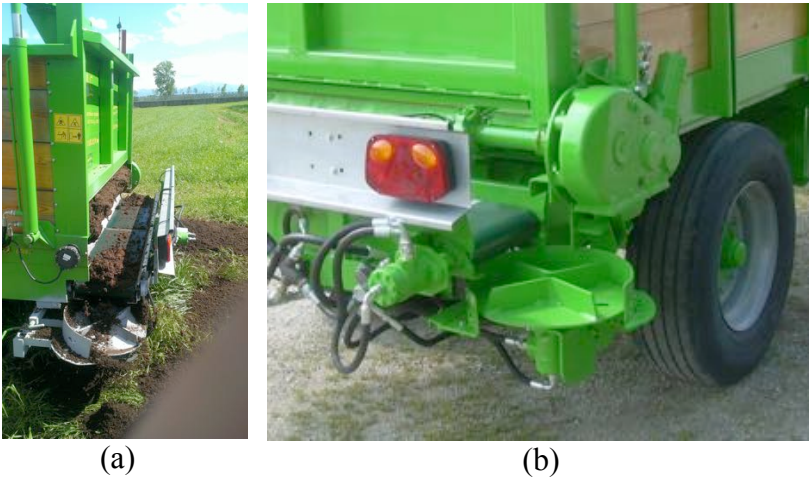
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377 Fig. 2.
378

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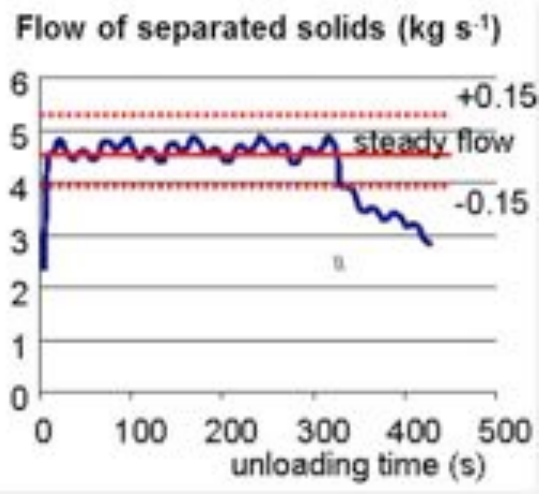
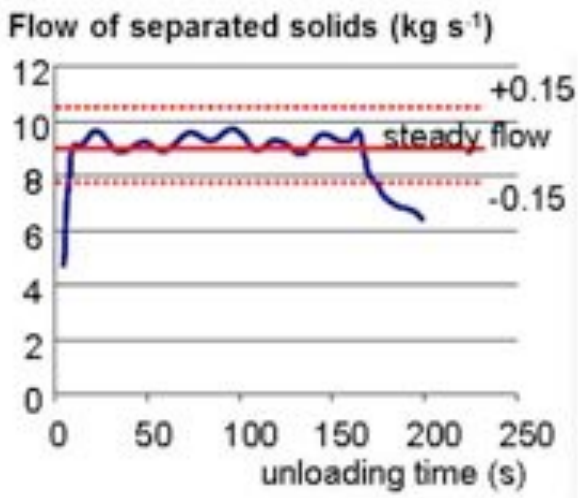


381 Fig. 3.



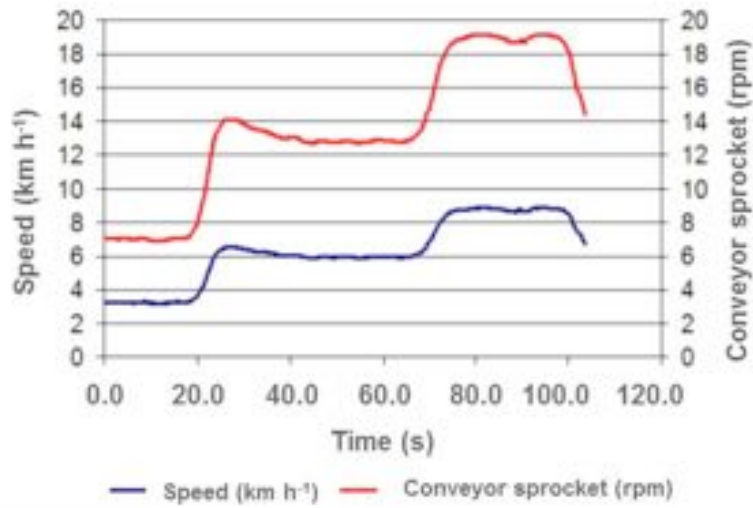
382 Fig. 4.

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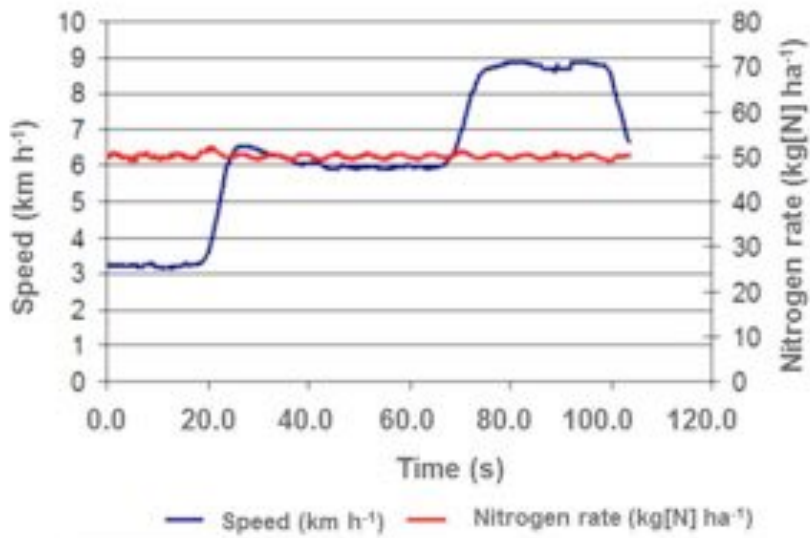
384 Fig. 5.

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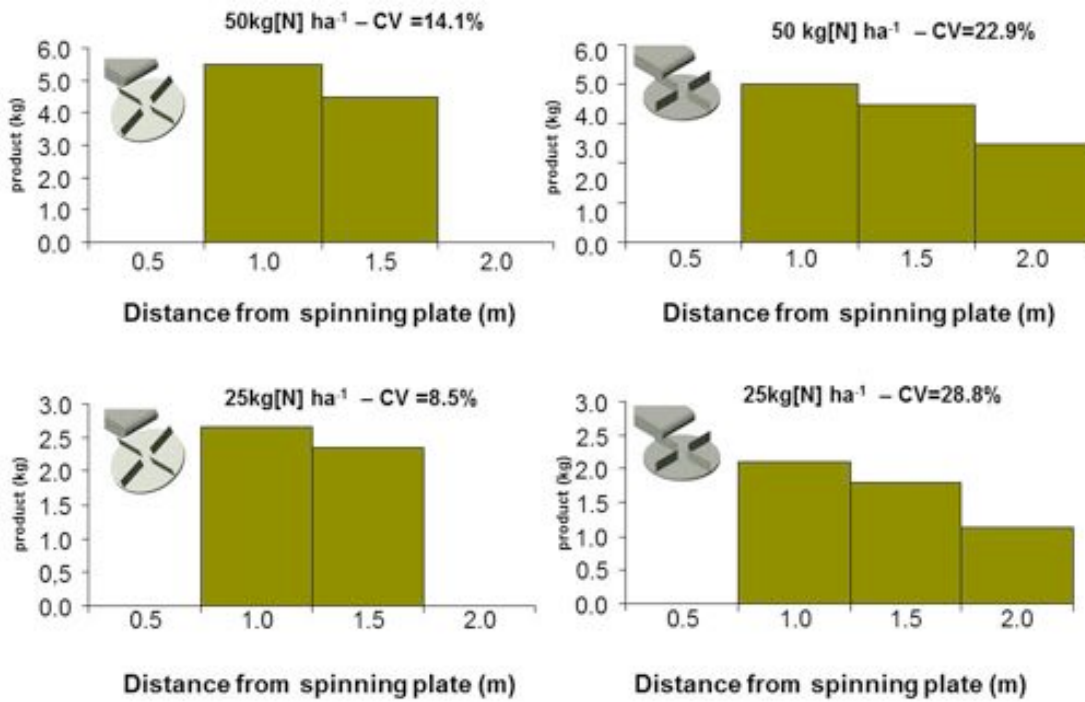
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387 Fig. 6
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391 Fig. 7
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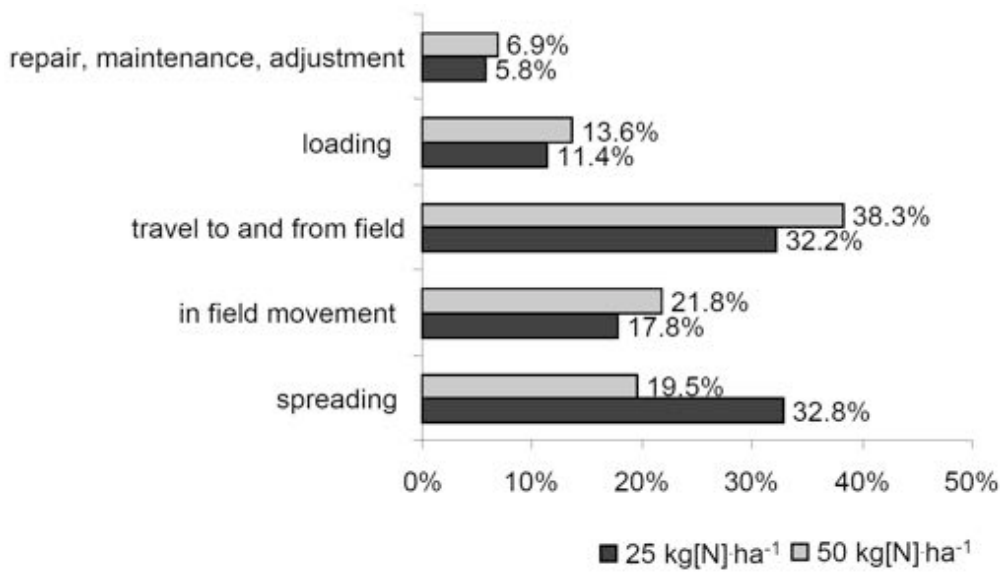
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395 Fig. 8.

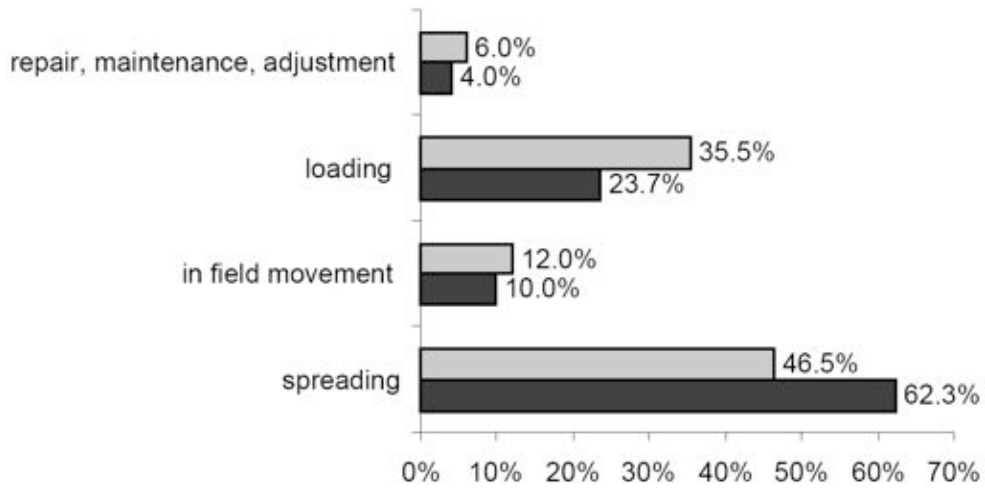
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398 Fig. 9.

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■ 25 kg[N] ha⁻¹ □ 50 kg[N] ha⁻¹ Fig. 10.

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402

403 Figure captions

404 Fig. 1. Separated solids spreader with application device and tree fertilization manure bands (dark
405 grey). Measurements in cm.

406 Fig. 2. Schematic of the automatic rate control system.

407 Fig. 3. Belt conveyors (a) and right spinning plate (b).

408 Fig. 4. Spinning plate at 0 ° (left) and 30 ° inclination (right).

409 Fig. 5. Flow of separated solids (3 kg [N] Mg⁻¹) during hopper unloading time in the case of a 4.0
410 m working width, 5.0 km h⁻¹ velocity, and application rates of 50 kg [N] ha⁻¹ (left) and 25 kg [N]
411 ha⁻¹ (right).

412 Fig. 6. Response time of the conveyor sprocket rotation vs the machine forward speed.

413 Fig. 7. The automatic rate controller allows a steady application rate. In this case, 40 kg [N] ha⁻¹ of
414 separated solids was applied with spreader forward speeds ranging between 3 and 9 km h⁻¹.

415 Fig. 8. Distribution patterns at different application rates and spinning plate inclines at 330 rpm.

416 Fig. 9. Incidence of different work times in field trial conditions. Total time: 25.9 min with the rate
417 of 25.0 kg [N] ha⁻¹; 21.8 min with the rate of 50 kg [N] ha⁻¹.

418 Fig. 10. Incidence of different work times in the case of in-field spreader tank load. Total time: 12.4
419 min with rate of 50.0 kg [N] ha⁻¹; 16.5 min with rate of 25.0 kg [N] ha⁻¹.

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