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Band application of slurry in orchards using a prototype spreader with an automatic rate controller

31

28

32 Fabrizio Gioelli*, Paolo Balsari, Elio Dinuccio, Gianfranco Airoldi

^a Department of Agriculture, Forestry and Food Sciences (DISAFA)– University of

34 Torino, via Leonardo da Vinci 44, 10095 Grugliasco (TO) Italy.

35 *Corresponding author. Tel. +39 011670884; Fax: +39 0112368844; E-mail address:

36 fabrizio.gioelli@unito.it

37

38 Abstract

39 A prototype slurry spreader for band application in orchards was designed, constructed, and tested. The spreader comprised several components: 1) 5 m^3 tank, 2) distribution 40 41 device of trailing hoses to reduce ammonia emissions during application, 3) automatic 42 rate controller to apply nitrogen per crop requirements, and 4) low-pressure, wide-43 section tyres to mitigate soil compaction and sward damage. The slurry tanker design 44 fitted between tree row spacings accounting for tree shape differences. The spreading 45 system consists of two groups of six trailing hoses; each hose group distributes slurry 46 into two 1.0 m wide bands alongside the machine and 0.5 m from tree rows. Operator 47 input of slurry total nitrogen content, determined by onboard hydrometer in the field, 48 and target application rate in the control unit ensured that nitrogen was applied at a 49 constant rate based on metering pump rotational speed as a function of machine forward 50 speed. The rate control system was tested at different application doses and with rapid changes in machine forward speed (range of 3-9 km h⁻¹). The machine responded 51 52 promptly (< 2 sec) to forward speed changes, and the spreader evenly distributed slurry

53	in both application bands ($D_{ave} < 2.5\%$ on the treated surface). Band application of
54	slurry by the trailing hose device reduced ammonia emissions by 63% compared to the
55	common broadcast application system by splash plate.

57 Keywords: automatic rate control, orchards organic fertilisation, slurry band

58 application.

59

60 Nomenclature

Ν	nitrogen
NH ₃	ammonia
N ₂ O	nitrous oxide
Q	nitrogen application rate, kgN ha ⁻¹
q	pump flow rate, 1 min ⁻¹
W	row spacing - working width, m
F	forward speed, km h ⁻¹
ha	hectare
TS	total solids
TN	total nitrogen
Dave	Average deviation
$\mathbf{X}_{\mathbf{i}}$	amount of slurry in one container, kg
n	number of containers of each group of trailing hoses
\overline{X}	average amount of slurry in containers of each group of trailing
	hoses, kg
cv	cultivar

CEC	cationic exchange capacity
cmol	centimole
TKN	total Kjeldahl nitrogen
TAN	total ammonium nitrogen

62 **1. Introduction**

63 The agricultural livestock sector produces large amounts of liquid slurry that possesses 64 substantial potential fertilisation benefits when properly used as manure (Chambers et 65 al., 2000; Schröder, 2005). In Europe, animal slurries are mostly applied on grasslands 66 and cereals (Jackson & Smith, 1997; Sieling et al., 1997; Rotz et al., 2004; Ceotto & 67 Spallacci, 2006), less frequently in horticulture (Cushman & Snyder, 2002; Ribeiro et 68 al., 2007), and uncommonly in orchards (Monge et al., 2000; Domínguez et al., 2010; 69 Cerutti & Beccaro, 2012). Concomitant with its value as a fertiliser, the nitrogen (N) 70 surplus (difference in N between inputs to soil and removals by crops) of the slurry can 71 pose serious environmental risks not only to ground waters from nitrate leakage, but 72 also to the atmosphere from gaseous losses of ammonia (NH₃) and nitrous oxide (N₂O) 73 (Webb et al., 2013).

The western Po Valley of Italy is characterised by high livestock density farms from which most pig farmers wish to export their excess N to other farm areas. Orchards where animal manures are generally not applied represent an opportunity to improve N utilisation in soils that often suffer from progressive reduction of soil organic matter content (Cerutti et al., 2011). In the Piedmont region of northwest Italy, at present there are more than 63,000 ha of orchards that often lie very close, less than 7 km, to intensive livestock farms. Slurry transport to such areas could be feasible by high volume slurry tankers or lorries (Balsari & Airoldi, 1991) and it could be applied with
spreaders capable of applying specific, generally low, amounts of nitrogen (< 50 kg [N]
ha⁻¹) (Jordan et al., 2011). The slurry spreaders would need to fit within narrowly
spaced rows (usually 4 m wide), provide even manure distribution, and minimise
nutrient loss and soil compaction (Botta et al., 2008).

86 Currently, despite the large area of orchard in the region, no existing slurry spreader fulfils these requirements. Low capacity (< 4 m^3) slurry spreaders equipped with a 87 88 splash plate are occasionally used, but a Department of Agriculture, Forestry and Food 89 Sciences (DISAFA) experiments (internal report) trials have shown their application 90 evenness, rate control, and NH₃ losses all to be very poor. In order to address the need 91 for suitable machinery, a prototype slurry spreader was designed and constructed within 92 the IMPREZA project (Italian acronym for: "Possibility of Reutilising Pig Manure in 93 Fruit Production"), financed in Italy by the Piedmont region. According to the project 94 plan, functional trials were performed to assess the technical and environmental 95 performance (in terms of NH₃ emissions) of the developed prototype.

96

97 2. Materials and methods

98 2.1 Definition of the application surface

99 Prior to development of the slurry spreader, the available literature was reviewed to 100 identify the target application area among the orchard rows, as well as the target 101 application rate. Tree fertilisation is optimised when slurry is applied for efficient root 102 up-take of nutrients, which Baldini (1986) and Baldoni et al. (1992) indicated is done in 103 a band approximately 1.0 m wide and 0.5 m away from the tree row (s1). Furthermore, band application avoids contact between slurry and trees, which limits the risk of plantdisease development.

106 The literature also revealed that the proper N application rate depends on the orchard 107 cultivar and age (Rufat & Dejong, 2001; Chatzitheodorou et al., 2004). For a peach 108 orchards, widespread in the western Po Valley, it ranges between 50 and 120 kg [N] y⁻¹ 109 (PSR, 2006). To obtain maximum organic fertilisation efficiency, about 70% of the rate 110 must be applied in early spring and the remaining 30% in summer (Baldi et al., 2010; 111 Baldi et al., 2012). According to these latter considerations, the slurry spreader was 112 designed to apply slurry in two 1.0 m wide bands beside the machine and 0.5 m from 113 the tree rows. A metering device with the ability to meet the application rates mentioned 114 above was developed later.

115

116 2.2 The prototype slurry spreader

117 The slurry spreader was designed to work autonomously and to operate in the narrow

118 row spacing (4 - 5 m) characteristic of orchards in northwest Italy.

119

120 The spreader contains several components (Fig. 2):

121 - box-section shaped steel frame;

122 - 5 m³ galvanized steel tank equipped with a slurry level sensor;

123 - non-steering axle fitted with wide section and low pressure tyres (500/60 -22.5) to

reduce soil compaction and sward damage (Keller & Arvidsson, 2004; Hamzaa &

125 Anderson, 2005);

126	-	hydraulic-driven	volumetric	lobe	pump	(Vogelsa	ng R140,	made	by	Hugo
127		Vogelsang Masc	hinenbau Gi	nbH,	Holthög	e, Essen,	Germany)	equippe	ed v	vith a
128		rotation speed ser	isor;							

129 - band spreading device consisting of a rotary distributor and 12 hoses (6 each side)

130 mounted on a hydraulically-actuated frame to place slurry 0.5 m from tree rows;

- automatic rate controller provided by DICKEY-John[®] Corporation, Auburn, IL,
 USA which has three main components (Fig. 3):
- proximity sensor for determining spreader forward speed, mounted on right
 wheel rim of the spreader;

• central electronic unit for operating parameter control and application;

control panel to set and verify operating parameters (forward speed, N
application rate).

At setup, the operator inputs several parameters into the control panel: row spacing (working width (m)), manure nitrogen concentration (kg [N] m⁻³), and target application rate (kg [N] ha⁻¹). The manure N content (kg [N] m⁻³) is estimated indirectly by the hydrometer method (Zhu et al., 2003), which utilises the linear relationships between the density and N content of the slurry as described by Piccinini & Bortone (1991). This method is not only simple, inexpensive, and reliable compared to other methods (Scotford et al., 1998; Saeys et al., 2005), but it is also accurate enough for our purpose.

146 The on-board computer calculated the application rate of the spreader per the following147 equation:

148
$$Q = 0.6 \cdot \frac{q \cdot N}{W \cdot F} \tag{1}$$

- 149 where
- 150 Q = is the nitrogen application rate (kg [N] ha⁻¹),

151 q = is pump flow rate (1 min⁻¹),

- 152 W = is row spacing or working width (m),
- 153 F = is forward speed (km h⁻¹), and
- 154 N = is estimated nitrogen content in the slurry (kg [N] m⁻³).

155 The automatic controller adjusts the slurry rate according to spreader travel speed and 156 working width. The system verifies that the applied application rate matches the target 157 rate by determining the rotating speed of the volumetric pump and, if necessary, 158 adjusting it by acting on the hydraulic engine linked to the lobe pump shaft. The 159 spreading system consisted of two groups of six trailing hoses, spaced 0.2 m from each 160 other for a total band spread width of 1.0 m for each group. Each hose group is mounted 161 atop a frame and the two frames are actuated by a hydraulic piston, so that they can be 162 spaced up to 1.0 m aside the tanker. This configuration allowed the tanker to be 163 properly positioned for band application to rows of different spacing and trees of 164 various shapes (Fig. 4).

165 A machine with multiple width settings addresses the needs for slurry application in 166 most of the orchards in the western Po Valley which are characterised by rows spaced 4 167 m (peach) and 5 m (hazelnut) apart. A band application design also minimises NH₃ 168 emission during land application (Malgeryd, 1998; Smith et al., 2000; Misselbrook et 169 al., 2002). The slurry manure was delivered to the trailing hoses using the volumetric 170 pump (Fig. 5a) through a rotary distributor (Fig. 5b) positioned on the spreading device. 171 Each trailing hose could be closed by a spherical valve to limit distribution to one side 172 of the machine when necessary.

174 2.3 Functional trials

Transverse and longitudinal distribution uniformity was evaluated following European Standard EN 13406 (2002) requirements. Experiments were carried out to verify the accuracy of the automatic rate controller (Scotford et al., 2001). For these tests, pig slurry from a fattening room of a farrow-to-finish farm was employed with a density of 1014 kg m⁻³, a total solids (TS) content of 27.2 kg m⁻³, and a total nitrogen (TN) content of 3.0 kg m⁻³.

181

182 2.3.1 Transverse distribution evenness

183 The replicated tests were performed on an even, horizontal surface and at three application rates (25, 50, and 100 kg [N] ha⁻¹). To collect the slurry, 0.30 m³ containers 184 185 were used. The pump was activated and run until constant slurry was delivered from all 186 the hoses, at which point containers were placed under each hose on both sides of the 187 machine. The time required to fill about 90% of the container capacity was recorded, 188 and the collected slurry quantity was determined by weighing each container on an 189 electronic scale (Kern ECB 50K50, made by KERN & Sohn GmbH, Balingen, Baden-190 Württemberg, Germany; capacity 50 kg, accuracy 0.05 kg). The data were then 191 processed in order to obtain the distribution pattern of trailing hoses. For each transverse distribution test performed, the average deviation (D_{ave}) was calculated by: 192

193
$$D_{ave} = 100 \cdot \frac{1}{n \,\overline{X}} \sum_{i=1}^{n} \left| X_i - \overline{X} \right|$$
(2)

194 where

- 195 D_{ave} = is the average deviation (%),
- 196 X_i = is the amount (kg) of slurry in one container,

197 n = is the number of containers of each group of trailing hoses and

198 \overline{X} = is the average amount (kg) of slurry in containers of each group of trailing hoses 199 given by:

$$200 \qquad \overline{X} = \frac{1}{n} \sum_{i=1}^{n} X_i \tag{3}$$

201

202 2.3.2 Longitudinal distribution evenness

203 Slurry flow was determined by registering changes in unit mass and the associated elapsed time from test start for changes of 5 kg s⁻¹ or less. A portable single axle 204 weighbridge scale (Sinergica[®] model WWSD10T, made by Sinergica Soluzioni S.r.l., 205 206 Montesilvano, Pesaro, Italy) with a 10,000 kg capacity accurate to 1 kg was used for this purpose. The automatic rate controller was forced to apply 50 and 100 kg [N] ha⁻¹ 207 (appropriate for a 4 m working width and a 5 km h⁻¹ forward speed), and the scale 208 209 control device was set to record weight every 5 s during tank emptying. The tests took 210 place on a slurry tank-filling platform near an above ground storage unit as the slurry 211 was discharged into a mixing pit.

212

213 2.3.3 Automatic rate controller accuracy

A series of tests was conducted to assess the precision and response time of the automatic rate controller to variations in spreader forward speed. The tests were performed by placing the spreader wheel with a proximity sensor on a hydraulic-driven roller device to simulate forward speeds between 1.0 and 10.0 km h⁻¹. A data logger recorded the signals from the wheel proximity sensor and from the speed sensor mounted on the lobe pump shaft. Three N application rates (20, 40, and 60 kg [N] ha⁻¹) were set on the central unit and tested independently as forward speeds were set to 3.0and gradually increased to 5.0 km h^{-1} , and then again from $5.0 \text{ to } 9.0 \text{ km h}^{-1}$. The response of the lobe pump to the forward speed changes was continuously recorded throughout the various settings.

224

225 2.4 Slurry application and measurement of ammonia emissions

226 The prototype was used for slurry application to a peach orchard (cv Spring bright, orchard design 1.80 m^x 3.90 m). Pig slurry was collected from a storage tank at a 227 228 fattening house of a farrow to finish farm. Prior to field application, the slurry 229 underwent hydrometer analysis to determine its N content. The resulting N content, 230 along with the required application rate and N content, were then input into the central 231 unit. The slurry was applied during the latter half of both April and June on two plots 232 (total surface: 3200 m^2). To confirm that the spreader delivered the required application 233 rate, it was weighed before and after each of the two distributions. Application rates and 234 estimated N content of the slurry are reported in Table 1.

235

	1 st application	2 nd application
Nitrogen application rate (kg [N] ha ⁻¹)	56	10
Nitrogen content of the slurry (kg [N] m ⁻³)	4.0	3.1

Table 1 – Peach orchard trials: application rates and estimated nitrogen content of the
slurry (hydrometer method).

238

After the second slurry application, NH₃ emissions were measured using wind tunnels
(Dinuccio et al., 2012). The resulting NH₃ emissions were compared from three

241 different application techniques: 1) band application by trailing hoses, 2) band 242 application by trailing hoses followed by immediate soil incorporation, and 3) the 243 common broadcast application system by splash plate. Slurry was incorporated into the 244 soil manually by shovel to a depth of 0.10 m. An adapted slurry spreader equipped with 245 a lateral splash plate was utilised for common broadcast application. The peach orchard soil was silt loamy sub-acid soil with 0.11% TN, 28.7 cmol kg⁻¹ cationic exchange 246 247 capacity (CEC), and pH = 6.4. All treatments were applied in triplicate in a randomised block design. The experimental area used for NH₃ emission trials was 176 m², divided 248 249 into nine, parallel plots of 19.5 m² (3.90 m \times 5.00 m) each. Two wind tunnels per plot (n = 6 per treatment) were used. Each wind tunnel covered a surface of 0.32 m² (0.80 m 250 length ^x 0.40 m width). Immediately following manure application, the wind tunnels 251 252 were placed over the plots and measurement began. Soil surface air velocity was adjusted to 0.6 m s^{-1} (Dinuccio et al., 2012) and samples were measured daily over 96 h. 253 During the tests, environmental temperatures were recorded daily with a Hobo[®] Onset 254 255 (Onset Computer Corporation, Bourne, Massachusetts, USA) data logger. Three 256 samples per load of applied manure (n = 3 per treatment) were taken for laboratory 257 analysis of TS, total Kjeldahl nitrogen (TKN), total ammonium nitrogen (TAN), and pH according to standard analytical methods. Specifically, TS were determined by drying 258 100 g of fresh material in a oven at 105 °C to a constant weight; TKN and TAN were 259 analysed by the Kjeldahl standard method (AOAC, 1990), and pH was determined by 260 261 pH-metre HI 9026 (Hanna Instruments, Italy).

Ammonia emission data were processed by ANOVA. When significant, the means were separated using the Tukey post-hoc test. Treatment differences were accepted if p<0.05.

- 266 2.5 Slurry spreader productivity
- 267 The following were recorded during orchard application:
- effective field time (i.e. time of slurry distribution);
- in-field displacement time (i.e. machine time in the field with the metering system
- turned off, such as travel within the field and turning time);
- travel time (i.e. travel to and from field, farmstead movement to reach slurry basin);
- loading time (i.e. time required for tank filling);
- 273 time for repair, maintenance, and setting the machine.

Collecting these data allowed determination of field efficiency (%), effective field capacity (ha h⁻¹), and effective material capacity (m³slurry h⁻¹), according to ASAE Standard EP496.3 guidelines (ASABE Standards, 2010). These data allowed development of a worksheet to value the effect of different operating conditions on machine efficiency, and alternative options for transport and distribution chains suitable for pig slurry delocalisation in orchard areas.

280

281 **3. Results and Discussion**

282 3.1 Transverse distribution evenness

As shown in Fig. 6, the spreading system produces an even application of slurry while operating with a D_{ave} of less than 3%. The ability to spread slurry uniformly and simultaneously on both sides of the machine is an important advance in spreader technology. The calculated D_{ave} values of 0.30%, 1.89%, and 2.47% for N application rates of 100, 25, and 50 kg [N] ha⁻¹, respectively, was based on total slurry flow rates from both groups of trailing hoses.

3.2 Longitudinal distribution evenness
Test results highlighted the steady flow of slurry (Fig. 7) that was attained during tank
unloading under both (50 kg [N] ha⁻¹ and 100 kg [N] ha⁻¹) tests conditions. A steady
slurry flow during tank emptying produces a longitudinal distribution unaffected by
slurry level into the tank, a basic requirement for proper application rate control.
3.3 Automatic rate controller accuracy

298 The tests also highlighted accurate signal reading by the various control unit sensors,

and sufficiently precise management by the control system (solenoid valves that control

300 the hydraulic system) that activates the lobe pump engine. The automatic rate controller

301 demonstrated its ability to adjust pump rotation speed quickly after machine forward

302 speed changes. Indeed, as the slurry spreader forward speed moved from 3.0 to 9.0 km

 h^{-1} , the system adjusted the pump rotation speed in less than 2 s (Fig. 8).

304 The system applied slurry at 40.0 ± 0.2 kg [N] ha⁻¹, even with two variations in forward

305 speed that required about 10 s each to restore the proper application rate (Fig. 9).

306 Similar results were obtained with application rates of 20 and 60 kg [N] ha⁻¹.

307

308 3.4 Slurry application and measurement of ammonia emissions

309 The automatic rate controller enabled the operator to apply the desired amount of N

310 regardless of spreader forward speed. Measured N application rates were 2.9% (first

311 test) and 3.8% (second test) higher than those targeted (Table 2).

312

	Application rate		
	target	measured	
	kg [N] ha ⁻¹	kg [N] ha ⁻¹	
1 st application	56	57.6	
2 nd application	10	10.4	

Table 2 – Target and obtained application rates obtained during field tri

Table 3 shows the chemical characteristics of the slurry used for NH₃ emissions testing.319

		TS	TKN	TAN
	рН	kg m ⁻³	kg m ⁻³	kg m ⁻³
Band application	7.5	30.5	2.89	2.09
Band application + harrowing	(0.07)	(0.66)	(0.08)	(0.07)
Splash plate	7.3 (0.04)	31.2 (0.54)	2.95 (0.06)	2.17 (0.06)

³²⁰ Table 3 – Main chemical and physical characteristics of the slurry used for NH₃

321 emissions testing (standard error in parentheses, n=3)

322

323 During NH₃ emission measurement, the average environmental temperature was 22.4°C 324 (range 16.3-28.8 °C) with an average relative humidity of 78% (range 55-100%). Total 325 N lost as NH₃ from broadcast application by splash plate was 10% of the total N applied 326 (Fig. 10). Band application of slurry significantly reduced NH₃ emissions, and were just 327 below 3.7% of applied N. Slurry incorporation following band application reduced 328 emissions the most, 2.7% of the N applied, although this result was not statistically (p > 329 0.05) different from that obtained by band application (Fig. 10). Harrowing after band 330 application is not always feasible due to the possibility of sward and root damage.

332 3.5 Slurry spreader productivity

333 The distance for transport of the slurry between the basin and the field averaged 1450 m. During the first slurry application, 57.6 kg [N] ha⁻¹, the spreader averaged 6.2 km h⁻¹. 334 The effective material capacity was 12.1 m³ [slurry] h⁻¹ and the effective field capacity 335 was 0.84 ha h⁻¹, equating to a 33.9% field efficiency (Fig. 11). During the lighter second 336 application, 10.4 kg [N] ha⁻¹, the spreader averaged 6.3 km h⁻¹. These values, combined 337 with an effective material capacity of 5.2 m³slurry h⁻¹ and an effective field capacity of 338 1.54 ha h^{-1} , yielded a 61.0% field efficiency (Fig. 11). 339 The low field efficiency calculated for the higher (57.6 kg [N] ha⁻¹) application rate was 340 341 mainly due to the impact of time spent travelling to and from the field, as well as 342 moving within (Fig. 10). Optimising spreader runs in the field (i.e., avoiding the down

time caused by returning to the slurry storage basin by refilling the tank spreader in the field) may increase field efficiency by 57.2% and 73.1% at application rates of 57.6 kg [N] ha⁻¹ and 10.4 kg [N] ha⁻¹ (Fig. 12), respectively.

346 To load the tank spreader in the field, a proper transport chain from the storage basin to 347 the field needs to be created for an effective material capacity, defined as equal to or 348 greater than that of the slurry spreader. In the case of a spring slurry distribution at 57.6 kg [N] ha⁻¹, the transport chain must operate with an effective material capacity of at 349 least 20.4 m³ h⁻¹. For the case of a three-axle vacuum tank of 15 m³ (the maximum legal 350 351 gross weight for Italy: 20 Mg) and temporary storage in a field edge slurry mobile container of 20 m³, the transport distance must equal less than 7.7 km (Fig. 13). 352 Similarly, a 16 m³ pump tank mounted on a three-axle truck (maximum legal gross 353 354 weight for Italy: 25 Mg) could operate at a maximum transport distance of 13.1 k.m.

and a 26 m³ pump tank mounted on a three-axle semi-trailer combination (maximum
legal gross weight for Italy: 44 Mg) could operate at a distance of 28.0 km.

357

358 4. Conclusions

359 Under our test conditions, the developed prototype slurry spreader was shown to be a 360 reliable machine for slurry application in orchards for three principle reasons: 1) proper 361 nitrogen quantity application due to the efficacy of its automatic rate controller; 2) 362 uniform slurry spread due to the performance of the metering pump and rotary 363 distributor; 3) low environmental impact as a result of reduced ammonia emissions 364 during slurry application. To confirm these results, additional trials shall be performed, 365 using different manure types in orchards planted with different soils and trees of varying 366 training systems. A full evaluation of the machine, including the environmental impact 367 of gases other than NH₃ (e.g., nitrous oxide), slurry nutrient leaching, and soil quality as 368 well as a comparison with manure application costs relative to other techniques, is 369 already under study by our research group.

Under our test conditions, the highest application rate (57.6 kg [N] ha⁻¹) reduced field efficiency as a result of low spreader tank capacity. Field capacity can be increased, however, by filling the slurry spreader in the field, and by choosing a proper transport and temporary storage chain. The need to suitably match the transport chain with specific machines/implements for the greater distances associated with more remote orchards requires agricultural contractors to provide high capacity transport tanker trailer systems and mobile field-edge slurry containers.

377

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488 Fig. 1.



492 Fig. 2







b

a

498 Fig. 4



b



- 501 Fig. 5
- 502













Fig. 9

Time (s)



518 Fig. 10









524 Fig. 12



529 Figure captions

530 Fig. 1 Slurry spreader with application device and bands (dark grey) of manure for tree

531 fertilisation. Distance m.

- 532 Fig. 2 Developed prototype slurry spreader with band application distribution system
- 533 operating in a peach orchard.
- 534 Fig. 3 Layout of the automatic rate controller.
- Fig. 4 Band application spreader at minimum (a) (transport position) and maximum (b)spacing.
- 537 Fig. 5 Lobe volumetric pump (a) and rotary distributor (b) with a spherical valve on
- 538 each hose.
- 539 Fig. 6 Transverse distribution patterns of band applicator hoses on the left (a) and right
- 540 (b) sides of the spreader.
- 541 Fig. 7 Flow of slurry recorded during the longitudinal distribution evenness trial at
- 542 application rates of 100 kg [N] ha⁻¹ (a) and 50 kg [N] ha⁻¹ (b).
- 543 Fig. 8 Response time of pump rotation speed *versus* machine forward speed.
- 544 Fig. 9 Response time of the automatic nitrogen rate controller vs. machine forward
- 545 speed in the case of an application rate of 40 kg [N] ha⁻¹ and a forward speed of the
- slurry spreader ranging from 3.0 to 9.0 km h⁻¹.
- 547 Fig. 10 Nitrogen losses after land application of slurry (data with the same letter are not
- 548 statistically different Tukey post-hoc test, p < 0.05).
- 549 Fig. 11 Different work times under field test conditions. Total time: 71.4 min ha⁻¹ at a
- 550 rate of 57.6 kg [N] ha⁻¹, and 39.0 min ha⁻¹ at a rate of 10.4 kg [N] ha⁻¹.
- 551 Fig. 12 Different work times of an in-field spreader tank load. Total time: 42.3 min ha⁻¹
- at the rate of 57.6 kg [N] ha⁻¹; 32.6 min ha⁻¹ at the rate of 10.4 kg [N] ha⁻¹.

- 553 Fig. 13 Maximum distance between slurry storage and orchard field for different
- 554 transport chains.