TEST OF AN AUTOMATIC RATE CONTROL SYSTEM FOR A CENTRIFUGAL-TYPE DRY FERTILIZER SPREADER

M. Fiala, R. Oberti

ABSTRACT. *A study was undertaken to investigate the accuracy of a commercial electronic system for the control of dry fertilizer application rate on a centrifugal spreader. The components of the electronic equipment, the logical sequence of the controller functioning and the test procedure are described. The system performance was evaluated considering three fertilizers with three nominal application rates, varying the spreader forward speed in the range 6-13 km/h and measuring the corresponding flow rates. The study was conducted under stationary conditions. The results show a good linear correlation between the fertilizer flow rate and the spreader work speed. The system accuracy, expressed by the distribution of the application rate error ε, was different for the three fertilizers tested. The optimal machine response was obtained with prilled urea (100% of samples affected with a ±10% application error), while the worst one occurred when using a compound of fertilizers (only 77% of samples within the application error range ±10%).*

Keywords. *Spreaders, Application rate, Fertilizer applicator, Control.*

The reasons for the growing adoption of electronic control systems in agricultural machinery concern the need to improve performance both quantitatively and in terms of quality. However, a quick look at the market shows that, although some applications have come into common use, others are still insufficiently considered. Certain devices (such as those for controlling grain losses in combines; automatic selection and grading of fruit and vegetables in harvesters; metering ingredients to prepare uniform cattle rations in feed-mixer wagons) have become standard accessories, while others, such as control devices installed on implements for the field-distribution of chemicals, remain uncommon (Ghate and Perry, 1994; Al-Gaadi and Ayers, 1994; Yu Li and Kushwaha, 1994).

This situation is surprising in view of the fact that these widespread implements play a primary role in terms of environmental impact. Consequently, controlling the quality of their operations is an objective of primary importance. In fact it helps to achieve the uniformity of product distribution and offers a practical method to reduce an excess of chemicals released into the ecosystem. The average quantities of fertilizers used in European agriculture are high (17.5 Mt/yr) and in the most intensive agricultural areas they exceed 100 kg/ha for nitrogen, 30 kg/ha for phosphorus and 30 kg/ha for potassium (Balsari and Airoldi, 1994).

Electronic control systems are the basis of variable rate technology (Paice et al., 1996), a key step towards precision farming, which represents one of the most important current subjects for agricultural engineering research (Stafford, 1997). Although the quantification of economic advantages (Grisso et al., 1989; Yule and Crooks, 1996) is still an open question, the adoption of machines equipped with automatic rate controllers offers undoubted ergonomic and safety advantages. In fact, controlling the operative parameters of the machine from the tractor cab avoids stopping the tractor and manually adjusting the distribution system. Taking into account the lack of experimental data, it seems important to evaluate the accuracy of the automatic rate controllers mounted on fertilizer spreaders. This objective appears particularly interesting due to the fact that experimental tests on metering the flow of granular materials are less common than for liquids. Within this specific goal, the Institute of Agricultural Engineering of the University of Milan carried out a set of experimental tests on a commercial electronic device designed to achieve the required application rate, by off-setting the work speed variations during the field operations. The accuracy of the control system was evaluated by measuring the fertilizer flow rate when the work speed of the spreader was varied.

MATERIALS AND METHODS

THE SPREADER AND ITS ELECTRONIC CONTROL SYSTEM

The tested device is the AMADOS, a DPAE system (Distribution Proportional to Advancement Electronically controlled), installed on a conventional tractor-mounted centrifugal fertilizer spreader, manufactured by AMAZONE® (Hasbergen-Gaste, Germany). This machine, equipped with two distribution discs, is the ZA-M MAX 1500. The fertilizer flow from the hopper to the lower rotary disc is controlled by two slide gates. The first gate, directly driven by the hydraulic circuit of the tractor, shuts-on (or off) the opening and the second gate, driven by the electronic control system, meters the material. To obtain flow control, the movement of each metering gate results in

---

Article was submitted for publication in November 1998; reviewed and approved for publication by the Power & Machinery Division of ASAE in March 1999.

The authors are **Marco Fiala**, Assistant Professor, and **Roberto Oberti**, Graduate Research Assistant, University of Milan, Institute of Agricultural Engineering, Milan, Italy. **Corresponding author:** Dr. Marco Fiala, University of Milan, Institute of Agricultural Engineering, Via G. Celoria 2, 20133 Milan, Italy; phone: 39 02 23691420, fax: 39 02 23691499, e-mail: marco.fiala@unimi.it.

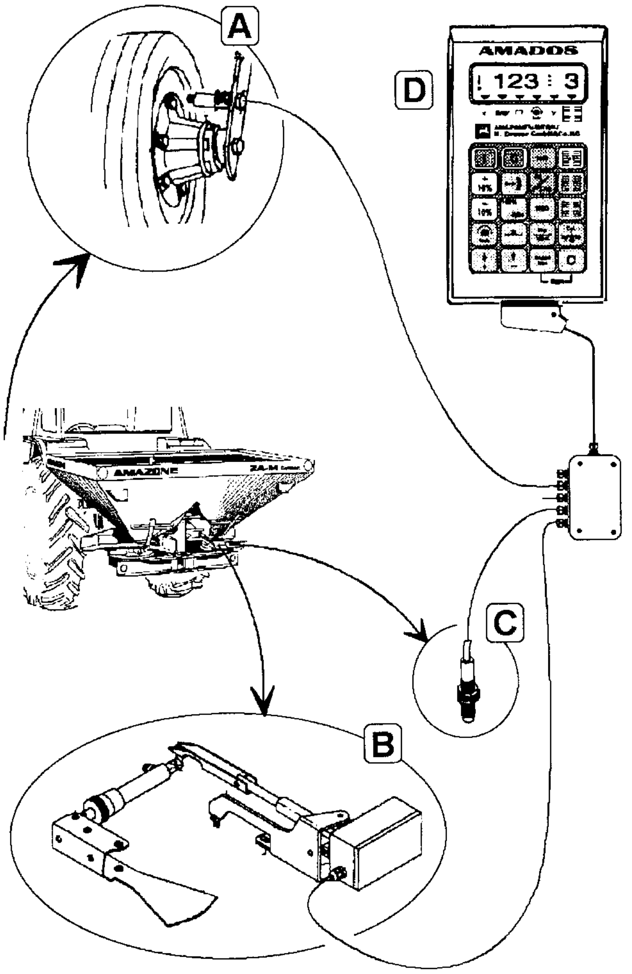


Figure 1–The electronic control system: work speed sensor (A); electric motor, linkage and metering gate for adjusting the outlet area (B); proximity sensor for detecting the opening of the hydraulic gate (C); on-board computer (D).

an angular opening α. The width of the angle α defines the outlet section.

For the specific fertilizer in use, the relationship between the outlet section and the material flow rate is determined by the calibration operation, prescribed by the manufacturer. The calibration procedure, which must necessarily be carried out before every field operation, provides for these steps:

- Opening the hydraulic-driven gates.
- Collecting the fertilizer mass discharged as the metering gates are positioned by the on-board computer at a predetermined opening angle α_c.
- Closing the hydraulic-driven gates.
- Measuring the fertilizer mass and inputting the value into the computer.

Based on the time of the gates opening and the discharged mass, the computer selects a "specific-fertilizer" flow function Q = f(α) to control the adjustment of the metering gates. Finally, after the calibration, the work width b(m) and the nominal fertilizer rate D_0 (kg/ha) must be entered into the computer and the automatic rate controller is ready to start, following this logical sequence:

- Measurement of the actual work speed v_a (km/h) of the spreader.
- Calculation of the fertilizer flow rate Q_0 (kg/min) corresponding to v_a and b in order to achieve D_0.
- Identification, using the flow function Q(α) set by the calibration procedure, of the angle α_0 corresponding to Q_0.
- Feed-back action on the opening angle: $\alpha_a \rightarrow \alpha_0$.

The components of the electronic equipment include (fig. 1) a work speed sensor, two electric motors, two proximity sensors, and an on-board computer.

The *speed sensor* is a magnetic field detector which generates an electric signal whenever a magnet passes in front of it. By placing six equidistant magnets on the front wheel of the tractor it is possible to obtain an impulse train whose frequency is proportional to the spreader work speed.

The *electric motors* work as actuators of the control system. They are connected to the metering gates which increase or decrease the opening angle α of the two outlets. The feed-back action on α is obtained through the rotation of the electric motor's shaft. The angular position of the shaft is detected by means of a sensor (photoelectric cell, slotted disc).

The photoelectric *proximity sensors* detect the condition (open or close) of the hydraulically operated gates which are controlled directly by the operator on the tractor. These sensors also alert that fertilizer distribution is in progress, thereby activating the on-board computer calculation functions.

Equipped with a keyboard and a display for the operator interface, the *on-board computer* permits the input of the selected operating data (nominal application rate, working width), puts the variables measured by the sensors into the control algorithm, and sends the actuation signals to the motors for real-time fertilizer metering. The display constantly shows the most important information concerning the operation currently in progress (actual work speed and application rate, opening of the hydraulic gates). The computer, whose size (20 cm × 10 cm × 7 cm) and weight (1.2 kg) allow it to be easily installed inside the tractor cab, also provides support information for the operator (field area covered, p.t.o. speed, etc.). Finally, the on-board computer is provided with some special functions such as:

- A "calibration function" that enables the calibration procedure previously described.
- A "rate step increasing/decreasing" that allows for a temporary variation in the application rate (by fixed steps of ±10% of D_0), which is useful for specific local field requirements.

THE FERTILIZERS

The tests were carried out using three commercial fertilizers with different physical characteristics; the granule sizes were determined with laboratory tests (table 1). The use of different fertilizers made it possible to evaluate the controller's versatility in relation to the different efflux characteristics of the materials.

EXPERIMENTAL PROCEDURE AND INSTRUMENTS

In the fertilizer distribution the application rate D (kg/ha), the flow rate Q (kg/min), the spreader working width b (m), and speed v (km/h) are correlated by the function:

Table 1. Physical characteristics of the fertilizers used in the tests

Characteristics	Compound Fertilizer N-P-K 15-15-15	Potassium Chloride KCl 0-0-60	Prilled Urea $(NH_2)^{++}$ 46-0-0
Apparent specific mass (kg/dm^3)	0.94	1.11	0.77
Absolute specific mass (kg/dm^3)	1.54	2.00	1.33
Granule size classes			
∅ < 1.25 mm	-	1%	23%
1.25 mm ≤ ∅ < 1.70 mm	1%	5%	25%
1.70 mm ≤ ∅ < 2.36 mm	8%	24%	47%
2.36 mm ≤ ∅ < 3.30 mm	60%	40%	4%
3.30 mm ≤ ∅ < 4.70 mm	29%	28%	1%
∅ ≥ 4.70 mm	2%	2%	-
SGN	31	32	18
Granule shape	Spherical	Irregular	Spherical

$$D = (600 \times Q) / (b \times v) \qquad (1)$$

It follows that (the working width being constant) if the work speed is varied, the application rate will remain equal to the nominal value only if a proportional variation in the flow rate is obtained. Therefore, the DPAE's function is to continuously vary the fertilizer flow in order to compensate for changes in speed. To ensure precise and accurate flow rate measurements and to simplify the procedure, experimental tests were carried out with the spreader stationary and the speed sensor mounted on a disc keyed to a 1.5-kW electric motor. Using a variable-pitch pulley speed variator it was possible to select the forward speed of the spreader (fig. 2). Because the specific goal of the tests was to evaluate the rate controller efficiency as a function of the speed variations, no other variables have been considered, such as those connected with in-field conditions (spreader vibration, soil slope etc.).

All the tests were carried out by setting a representative working width b = 16 m on the computer and keeping the level of fertilizer in the hopper constant (70% of maximum capacity). Eight different work speeds (from 6 to 13 km/h, in steps of 1 km/h), three nominal application rates (100, 200, and 300 kg/ha) and three types of fertilizer (compound fertilizer, potassium chloride, prilled urea) were tested in all combinations. Fresh fertilizer was used for each test. For each fertilizer, application rate and forward speed, the fertilizer mass discharged through both the right (m_R; kg) and left (m_L; kg) outlets, as well as the corresponding discharging times (t; s) were measured. Every measurement was replicated three times, for 432 samples in total. The fertilizer masses were measured by means of an electronic dynamometer (precision 50 g; sensitivity 20 g) and the discharging time by an analog chronometer (precision 0.1 s; sensitivity 0.1 s). Knowing the mass and the related time, the actual fertilizer flow rate Q_a (kg/min) was calculated. Whenever the fertilizer or the application rate were varied the automatic controller was calibrated; the average value of three measurements was set into the on-board computer.

Figure 2–The electric motor-reduction gear group used to set the spreader work speed. The picture shows also the on-board computer of the tested system.

Figure 3–Four containers placed on a trolley made it possible to simplify the fertilizer-collection procedure for determining the flow rate.

To avoid irregularities in fertilizer outflow under transient conditions, the fertilizer mass collection (from left and right outlets) started 5 s after the opening of the hydraulically operated gates; the collecting time was chosen in order to obtain samples with mass of 15 ± 5 kg. To this end, a manually moved trolley equipped with 4 containers was used (fig. 3). The fertilizer was collected into the first couple of containers (reject-containers) during the period immediately after the hydraulic gates were opened. As a steady flow was obtained, the fertilizer collection was transferred, by moving the trolley, to the other two contiguous containers (sample-containers), to achieve an approximate mass of 15 kg. Moving back the trolley, the sample collection was stopped and the fertilizer mass inside the right and left sample-container was measured. In addition, the influence of the fertilizer level inside the hopper on the accuracy of the system was investigated; this test was carried out using potassium chloride at the nominal application rate D_0 = 200 kg/ha and setting the work speed at v = 10 km/h. Similarly, the system accuracy was checked when the "rate step increasing/decreasing" function was used; this test was carried out with prilled urea at D_0 = 200 kg/ha for two different work speeds (v = 8 and 12 km/h). Finally, to evaluate the relation between the gates opening and the material flow for the tested fertilizers, the outlet area was measured while varying the forward speed. Images of the outlet were recorded by a video-camera and digitized by frame-grabber software on a PC. The outlet opening area was measured in pixels via the software and compared to a reference area (6.07 cm^2) placed, on the same plane of the outlet, inside the field of vision. No specific tests were carried out on response time of the rate control system.

RESULTS

As expected, the experimental results show a linear relationship between the actual fertilizer flow rate Q_a and the spreader work speed v; the significance of the correlation is indicated by the coefficient R^2, which is always greater than 0.977 (table 2). By applying the equation 1, the actual application rate D_a (kg/ha) through the two outlets is calculated and shown in figures 4, 5, and 6. The accuracy of the electronic control system is expressed by the application rate error ε, obtained by:

$$\varepsilon = (D_a - D_0) / D_0 \qquad (2)$$

Table 2. Actual flow rate versus work speed: linear regression coefficients R^2

	Left Outlet Nominal Application Rate D_0 (kg/ha)			Right Outlet Nominal Application Rate D_0 (kg/ha)		
	100	200	300	100	200	300
	R^2			R^2		
NPK	0.988	0.982	0.987	0.991	0.993	0.985
KCl	0.989	0.977	0.978	0.984	0.981	0.988
Urea	0.994	0.986	0.988	0.980	0.992	0.994

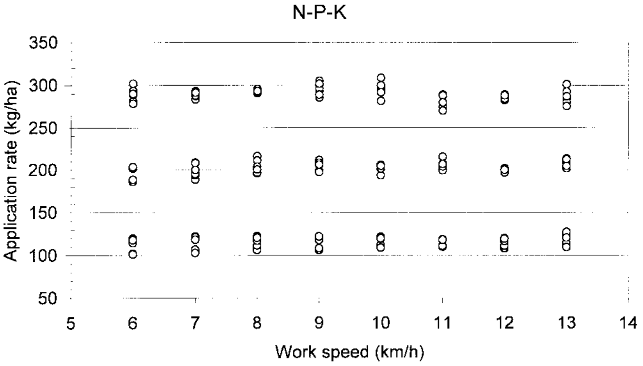


Figure 4–Compound fertilizer: actual application rate versus work speed. The straight line represents the nominal application rate.

The errors, calculated for the three fertilizers and for all the collected samples, were grouped in frequency classes, each of 2.5% width. Figures 7, 8, and 9 show the distribution functions; the patterns of these curves are clearly different.

The compound fertilizer exhibits a bimodal curve (fig. 7) as a result of the overlapping of the following two anomalous behaviors which can be identified in figure 4:

- A systematic over-dosage at D_0 = 100 kg/ha.
- Irregular responses at D_0 = 200 kg/ha and D_0 = 300 kg/ha.

The lack of accuracy in the control system was due to the high moisture content of a part of the material used during the tests; unfortunately, this non-optimal property

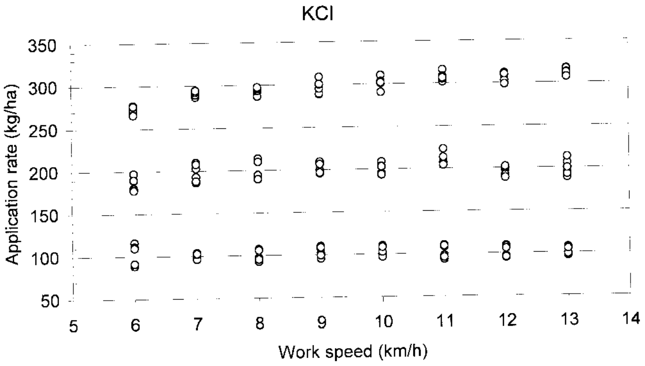


Figure 5–Potassium chloride: actual application rate versus work speed. The straight line represents the nominal application rate.

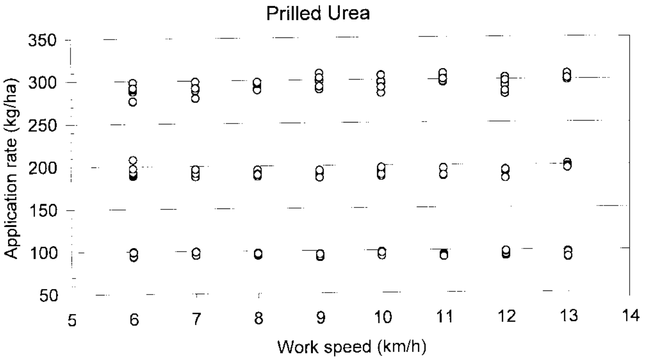
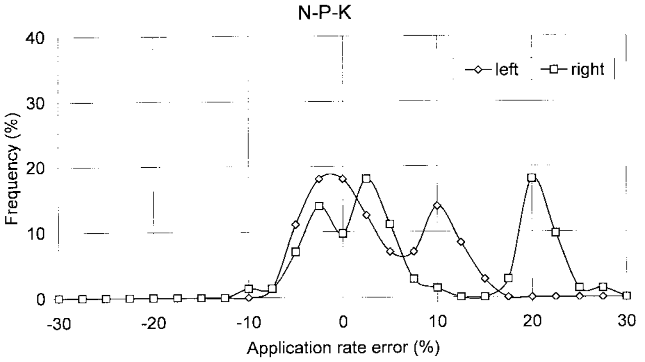


Figure 6–Prilled urea: actual application rate versus work speed. The straight line represents the nominal application rate.



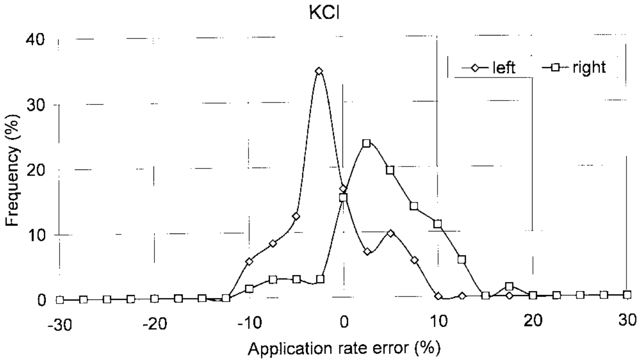
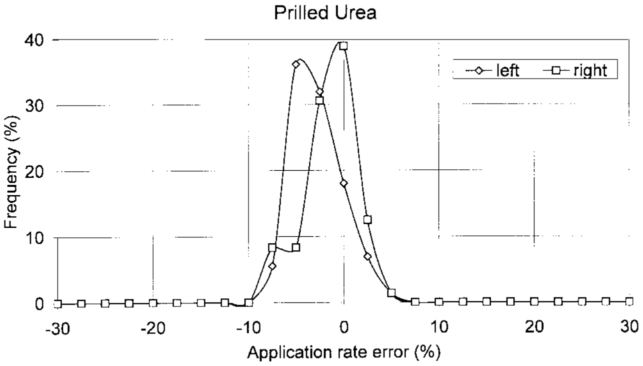


Figure 8–Potassium chloride: distribution of the application rate error ε.



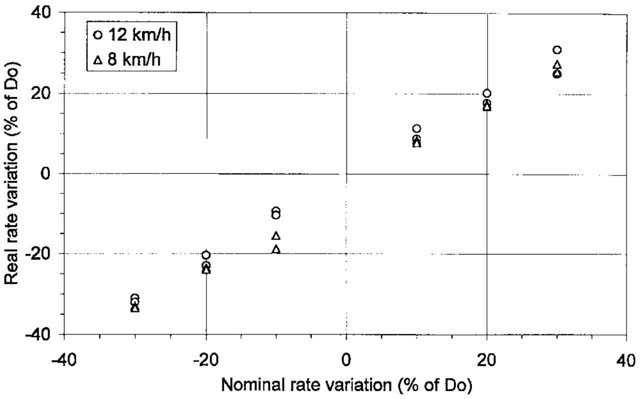


Figure 10–Rate step increasing/decreasing on-board computer function: obtained application rate variation versus nominal application rate variation (test conditions: fertilizer = prilled urea; nominal fertilizer rate D_0 = 300 kg/ha; work speed: 8 km/h and 12 km/h).

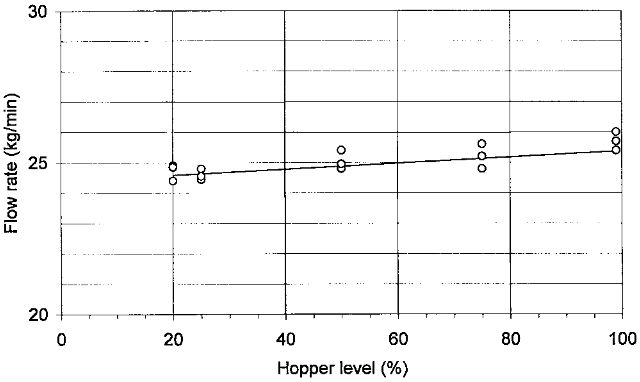


Figure 11–Potassium chloride: flow rate versus fill level of the hopper.

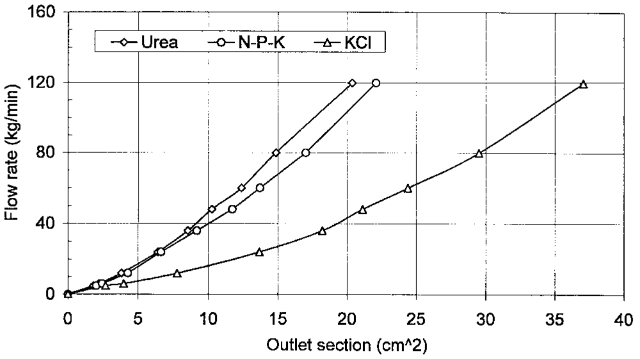


Figure 12–Outlet area versus flow rate (test conditions: nominal fertilizer rate D_0 = 300 kg/ha).

was noticed only at the end of the test. For this type of fertilizer only 77% of the total observations had an application rate error between –10 and +10%. However, potassium chloride had a unimodal distribution curve (fig. 8) and resulted in a relevant ($\bar{\varepsilon}_L - \bar{\varepsilon}_R = 6\%$) difference between the left and the right outlets. Irregular responses at D_0 = 300 kg/ha are evident (see fig. 5). More than 93% of the total observations gave an application rate error ranging from –10% to +10%.

The prilled urea had a very narrow unimodal error distribution (fig. 9), with low ($\bar{\varepsilon}_L - \bar{\varepsilon}_R = 1.5\%$) difference in the outlets behavior. A moderate trend to under-spread at every nominal application rate is recognizable (see fig. 6). All the samples had an application rate error within the range –10% to +10% for this ammoniacal fertilizer.

As regards the tests of the “rate step increasing/decreasing” feature, figure 10 shows the obtained rate variations. They are well correlated (R^2 = 0.967) with the nominal ones.

The experimental test showed that the hopper fill level significantly affected the fertilizer flow rate. For example, the difference between the flow rates obtained with a full hopper and hopper level of 20% was significant with $p < 0.015$. However, the influence of this factor was slight; from a full to a 20% charged hopper, the fertilizer flow rate decreased less than 4% (fig. 11).

Finally, figure 12 shows the relationship between fertilizer flow rate and outlet area. For homogeneous materials, such the prilled urea, the relation appears almost linear, while for fertilizer characterized by rough and non-spherical particles (e.g., potassium chloride) the curve assumes a quadratic shape, in order to compensate for the greater friction.

CONCLUSIONS

The tests to evaluate the operational accuracy of the AMADOS® electronic control system mounted on a ZA-M MAX 1500 centrifugal spreader manufactured by Amazone, at nominal application rates of 100, 200, and

300 kg/ha with forward speeds in the range from 6 to 13 km/h, showed that:

- The samples with an application rate error within the $-10\% < \varepsilon < +10\%$ range were:
  100%, for prilled urea
  93%, for potassium chloride
  77%, for compound fertilizer
- The performance of the control system was affected by high moisture content when applying the compound fertilizer.
- The hopper level slightly modified the fertilizer flow rate.

Finally, it should be stressed that the literature does not supply any standard methodology to test the operative efficiency of application rate control systems, nor any indices for summing up their functionality. The test procedure used in this study was found to be suitable for achieving the experimental goals, as well as being easy to manage and implement directly on the farm.

ACKNOWLEDGEMENT. The fertilizer spreader used for the experimental tests was provided by SAVE Spa, Lomagna, Italy.

REFERENCES

Al-Gaadi, K. A., and P. D. Ayers. 1994. Monitoring controller based field sprayer performance. *Applied Engineering in Agriculture* 10(2): 205-208.

Balsari, P., and G. Airoldi. 1994. *Spandiconcime* (fertilizer spreaders). Bologna, Italy: Edagricole.

Ghate, S. R., and C. D. Perry. 1994. Ground speed control of pesticide application rates in a compressed air direct injection sprayer. *Transactions of the ASAE* 37(1): 33-38.

Grisso, R. D., E. C. Dickey, and L. D. Schulze. 1989. The cost of misapplication of herbicides. *Applied Engineering in Agriculture* 5(3): 344-347.

Paice, M., P. Miller, and W. Day. 1996. Control requirements for spatially selective herbicide sprayers. *Computer & Electronics in Agriculture* 14(2,3): 163-177.

Stafford, J., ed. 1997. Precision agriculture. In *Proc. 1st European Conference*, Warwick (UK), 8-10 September. Oxford, England: BIOS Scientific Publ., Ltd.

Yu, L., and R. L. Kushwaha. 1994. A digital control system for variable rate nitrogen fertilization. *Computer & Electronics in Agriculture* 10(3): 245-258.

Yule, I., and E. Crooks. 1996. Precision farming: The price of imperfection. *Landwards* (Spring): 5-9.