Assessment of Two Variable Rate Irrigation Controllers used on a Centre-Pivot

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ABSTRACT

This paper reports on the contrasting patterns of two variable rate application systems used in precision irrigation: the pulse width modulation and the bi-model sequencing, on the distribution uniformities of the two systems and on the evaluation of their performance with regard to the different low operational pressures of 1, 1.5 and 2 bar. Twenty-one tests were conducted with 90- 130 measurements for each test. The two systems were tested statistically with a water diffusion plate. A pulse frequency of 3 cycle/minute operated in a duty cycle of 47-50% was used for the purpose of evaluation. The results were used to simulating three areas under the three spans of the centre pivot. The simulation was based on a single nozzle performance. The results of the different performance variables revealed that the pulse width modulation system performed more efficiently than the bi-model sequencing system throughout all tests and that the pressure of 1.5 bar was the lowest pressure that gave optimal results.

Key Words: variable rate irrigation, application uniformity, precision irrigation, centre pivot

1. INTRODUCTION

Under variable rate application (VRA), the uniformity of water application is a challenging issue since the centre pivot irrigation system (CP) does not apply the water evenly across the field due to the difference in area between the centre and the outside of the span. The application rate should adjust to the variations in the requirements of the management zone as well. Several research studies have been carried out on the use of an irrigation system with variable rate control systems: the pulse width modulation (PWM) whereby water from each jet is turned on and off in a rapid duty cycle and the bi-model sequencing (BMS) whereby alternate nozzles spray water sequentially. Evans *et al*, (1996), developed both software and hardware to control a centre pivot to deliver predefined water rates to reduce water usage and chemical leaching. To vary the input at non-uniform fields, McCann et al, 1997 used electrical solenoid valves and control modules to operate multiple sprinklers with different nozzle sizes. King and Kincaid (2004) developed and tested a variable flow rate sprinkler for site-specific irrigation management that included a cycling concentric pin placed into a sprinkler nozzle bore without significant adverse effect on the sprinkler radial application pattern. VRA was utilized to handle situations that were characterized by slope and by differences in soil water holding capacity, soil depth, crop type variation and natural and physical field barriers. The PWM and the BMS systems which were extensively used in precision irrigation were similar in their infrastructure as they basically had the same installation and maintenance costs but required different programming. King *et al.* (1999) introduced a computer digital control system for spatially varied irrigation and chemical application and implemented it on a commercial centre pivot. Different water application depths were obtained by pulsing the flow and varying the pulse cycle (DeBoer, 2001)**.**

Tarjuelo *et al.* (1999) observed that in almost all the tests conducted on the center pivot the major variability in uniformity was detected at the outer end. They recommended the use of a medium-size rain-gun or a sprinkler to overcome the problem of non-uniformity. The application efficiency of spray irrigation depends on the techniques applied to measure the depth of irrigation from the sprinkler device. To estimating the spray application efficiency, small collectors are less accurate than energy balance models, chemical tracers and the weighing lysimeter (Schneider, 2000). In the present study, all the experiments were conducted in the same setting and had a uniform design in order to minimize the errors associated with measurements and instrumentation settings and to facilitate the comparison between the two water application control systems.
The objective of this paper was to judge if the VRA system that could consume less energy in irrigated agriculture and yield the highest application and distribution uniformity and to evaluate the application uniformity and other performance characteristics of both PWM and BMS systems under various low pressure conditions.

2. MATERIAL AND METHODS

This study was carried out on a centre pivot at the Institute of Production Engineering and Building Research, the Federal Agricultural Research Center (FAL), Braunschweig, Germany. Two types of VRA systems were investigated under various pressure conditions in order to find out the highest uniformity application obtained with the lowest pressure. Uniformity evaluation was conducted to estimates potential water use. A constant pulse frequency with different nozzle orifices was selected from the CP and evaluated. The assessment tools utilized for the evaluation process were: the coefficient of uniformity

(CU), the coefficient of variation **(**CV), the mean application depth (MD) and the distribution uniformity **(**DU).

2.1 The centre pivot

The CP was 150m long and consisted of 3 spans. It included 50 sprinklers spaced at equal distance of 3m. The spacing between the nozzles was standardized by the manufacturers. The area covered by the individual sprinklers together with the sprinkler location varied with the radial position along the centre pivot. Each nozzle then had different speed; the nozzles were different in orifice size which ranged from 3.6 to 8.5 mm. Each sprinkler was attached to an individual solenoid and pressure regulator. The position of the sprinklers was determined by a digital angle resolver which was located at the central stationary point of the first span of the centre pivot. The theoretical accuracy of the angle resolver was 1°. This position measurement was likely to give a range of ±0.30 m error at the first tower position. That would lead to accumulated rather than offset error in the position of the successive spans. The centre pivot system was modified to use solenoid valves at each nozzle. These valves were controlled by a computer unit which could be programmed to turn the sprinklers on and off in each of the 360 locations at a specified time in the entire cycle of the CP. There was no end gun attached to the system.

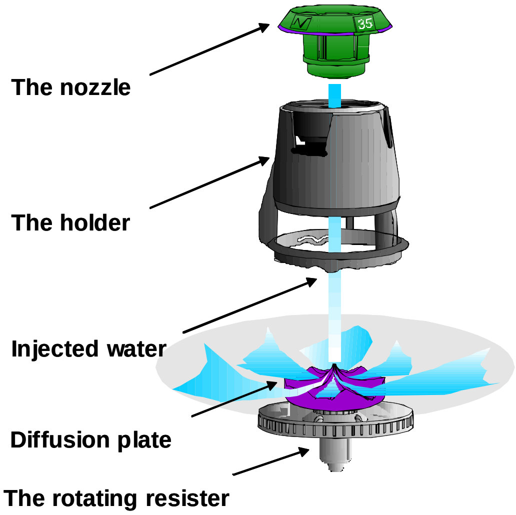

Figure 1. The sprinkler head components (Nelson, 2003).

2.2 Experimental setup and procedure

As field trials are prone to many errors, the variable rate tests were conducted in a purpose built spray laboratory. The catchment device was 120 cm above the floor, 720 cm deep, 1800 cm wide and 250 cm high. An array of 160 parallel furrows, each of which was 720 cm long 10 cm wide was used in this study to collect the water 1 m below the sprinkler head (Figure 1). This measuring device was more representative of the real field situation than the catch can which was positioned in one or more than one line and utilized for evaluating the system performance. Since the furrows collect all the amount of water sprayed by the nozzle heads, the sampling error of the furrows is fewer than that of the catch cans. This device also gives us a clear indication of the water distribution in two dimensions. The collected water was accumulated in 160 transparent cylinders each with a capacity of 2.5 L. The amount of water collected in each cylinder was accurately determined and recorded five minutes after the experiment was over to ensure that the surface water collected by the furrows was accumulated in the cylinders.

Tests that assessed the performance of the two water application control systems: the PWM, the BMS and the uniform application (UA) were conducted on sprinklers that were 100 cm above the furrows. The sprinklers were kept vertical throughout the test duration. They were mounted on an elevated lateral pipe and placed in the middle of the test chamber to ensure wide coverage area. Each sprinkler had a replaceable nozzle that was 1 cm above the rotating diffusing plate which was driven by the force of the water jet. Rotating spray plate sprinklers embedded a grooved spray plate which rotated under the effect of the water jet. The rotating plate had a certain rotation resistance adjusting its rotating velocity.
For the purposes of assessment, three manufactured nozzles (reference numbers 20, 30 and 40, Nelson Irrigation Company, R 3000 D4-8° orifice diameter was 4 mm, 6mm and 8 mm sequentially: the trajectory angle 8°, 4 Main Streams) were selected from the first, second and third span of the centre pivot and tested to get a realistic and representative picture of the spatial water distribution pattern. The nozzles had the performance characteristics of relatively large droplets, medium area of application coverage and low energy requirements. The pressure meter readings were used to adjust the control valves manually. Three meters were utilized for monitoring the pressure: the first was located on the main pump inlet next to the pressure control valve and prior to its outlet to the hose; the second was located on at the other end of the hose and the third was located before the sprinkler head. All the nozzles were tested under the same setting and procedure (wetting the test chamber, placing the sprinklers in a perpendicular position and adjusting the pressure as required before operating the solenoid) in order to avoid the bias and to facilitate comparison. Single-sprinkler distribution patterns were measured in the department of agriculture at FAL. Sprinkler flow rate and pressure were fixed to verify the intended performance. The sprinklers were tested on three constant low pressures: 1, 1.5, 2 bar (100, 150 and 200 kPa) since the objective was to promote energy conservation.

The PWM system was controlled to operate in a duty cycle of 47- 50% and in a pulse frequency of 3 cycle/minute. The BMS was also controlled to operate in a form that enabled the operator to stop all the solenoid valves that carried either a single or an even number. Each cycle included two phases: the on-operating phase of the irrigation system and the off- operating phase. The duration of the single cycle was 60 seconds including ten second on and ten second off. The solenoid valve which was mounted on each sprinkler head controlled the on-off nozzle water discharge. The solenoid valve opened and closed almost instantaneously- one solenoid valve was used for all the experiments in the test chamber in order to minimize the errors associated with changing the types and the regulator response times.

2.3 Testing conditions

The environmental factors (wind, air temperature and vapour pressure deficit) could influence the distribution patterns. Both the wind velocity and the temperature sensors were continuously monitored automatically during the experiment. The manometer which had an accuracy of ± 3% was also carefully monitored to ensure that no fluctuation in pressure would occur during the experiment. All the tests were carried out at night. There was no wind and the temperature was below 12 C°, which reduced evaporation losses. The radiation was low- it came mainly from artificial lighting. A total of 21 laboratory tests of sprinklers irrigation system were conducted. Each test had its own specified time which ensured that the collecting cylinders would not get flooded during the test. The timing was standardized for 60 seconds by dividing the amount of water collected in each cylinder on the time of each experiment. The test duration for each experiment was standardized at 60 seconds and the testing station was wetted before each experimental series in order to guarantee that the same conditions prevailed for all experiments. Water depth was recorded in the catch cylinders 20 min at the end of each experiment in order to allow the water in the furrows to drip into the cylinders.

2.4 The irrigation simulation model

Measured single-sprinkler distribution patterns were used in an overlapping sequence with specified sprinkler spacing scenarios to simulate multiple-sprinkler distribution patterns of the CP. The spacing scenarios were: the uniform application with a standard 3 m distance, the BMS system with a 6 m distance and the PWM system with a 3 m distance between the nozzle heads. The area of the collected water under the nozzles was simulated for 13 meter in length. A spreadsheet was used for conducting the simulation. Sprinkler water distribution depended on system design parameters such as sprinkler spacing, operating pressure, nozzle diameters and on environmental variables- wind speed and direction (Keller and Bliesner, 1990).

2.5 Sprinklers efficiency and distribution uniformity

Irrigation uniformity can be characterized by a coefficient which is calculated on the basis of water collected in catch cans or on the bases of changes in soil water content at a discrete measurement point in the field. As pointed out by Dechmi *et al.* (2003), irrigation uniformity was the most valuable outcome of the evaluation process in sprinkler irrigation. Several formulas were designed to describe the uniformity of the sprinklers water distribution and to evaluate their performance. The two formulas: Heermann and Hein Modified Formula (equation 1) and Christiansen Formula (equation 2) (ASAE Standards 2003) were applied in the evaluation process in the laboratory test of the present study. Heermann and Hein Modified Formula is:

$$\mathrm{CU_{HH}} = 100\left[1 - \frac{\sum_{n} \mathrm{S_s}\left|\mathrm{D_s} - \frac{\sum_{n} \mathrm{D_s S_s}}{\sum_{n} \mathrm{S_s}}\right|}{\sum_{n} \mathrm{D_s S_s}}\right] \qquad (1)$$

Where D_S is the total depth of application from a sprinkler system at a distance S_S from the centre of the rotation and S_S is the distance from the centre of the rotation to the point where D_S is measured. Christiansen Formula is:

$$CU_C = 100\left[1 - \frac{\sum_n \left|D_s - \overline{D}\right|}{\sum_n D_s}\right]. \qquad (2)$$

Where D is mean water depth collected, n is the total number of collecting furrows used in the evaluation.
$\overline{D}$ is the mean water depth collected by each furrow.
The CUc was used to assess the uniformity of a single nozzle distribution during the static test in the chamber.

To attain a satisfactory level of irrigation efficiency, high water uniformity was required (Dechmi *et al.* 2003). The application efficiency of spray irrigation can be conditioned by the density, the grid size and the adequacy of measurement collectors. The use of the distributional function to evaluate the CP could not specify which location on the field received the given amount of water. The mean application depth for the two types of application systems was identified for the purpose of comparison. The distribution uniformity according to Tarjuelo *et al* (1999a) means:

$$DU = \frac{\text{Mean Depth Caught on the fourth of the Field Receiving the Least Amount}}{\text{Mean Depth Caught on the Entire Field}} * 100$$

3. RESULTS

The three water application systems: PWM, BMS and UA were contrasted on the bases of three specified operating pressure 1, 1.5 and 2 bar at the nozzle elevation 1.0 m. as presented in Table 1. Table 2 shows the effect of the changes of the operating pressure on the wetted diameter for each sprinkler- the wetted diameter is defined for the purpose of this study as the distance between the furthest points that the sprayed water could reach provided that the water collected should not be less than tenth of the mean water application.. The assessment models CU_C, CU_{HH}, DU, CV and the Mean Application were adopted for the evaluation and comparison three water application systems.

Table 1. The CU_C[%], CU_{HH}[%], DU[%], CV[%]and the Mean Application Depth[mm] for sprinkle head height of 1m.

	Uniform Application (UA)						Pulse With Modulation (PWM)						Bi-Model Sequencing (BMS)					
pressure	**M**	**CV%**	**SD**	**CUc%**	**CUhh%**	**DU%**	**M**	**CV%**	**SD**	**CUc%**	**Cuhh%**	**DU%**	**M**	**CV%**	**SD**	**CUc%**	**CUhh%**	**DU%**
P. 1 Bar																		
Nozzle 20	**282**	**0.09**	**24**	**92**	**91**	**92**	**119**	**0.10**	**12**	**91**	**89**	**88**	**137**	**0.25**	**35**	**76**	**75**	**68**
Nozzle 30	**510**	**0.14**	**71**	**89**	**88**	**82**	**217**	**0.14**	**31**	**89**	**87**	**82**	**244**	**0.49**	**119**	**52**	**51**	**55**
Nozzle 40	**948**	**0.11**	**103**	**89**	**88**	**88**	**404**	**0.14**	**55**	**87**	**86**	**83**	**457**	**0.33**	**153**	**68**	**64**	**56**
P. 1.5 Bar																		
Nozzle 20	**377**	**0.23**	**88**	**78**	**76**	**76**	**160**	**0.12**	**20**	**90**	**88**	**87**	**195**	**0.36**	**71**	**69**	**67**	**70**
Nozzle 30	**745**	**0.17**	**128**	**83**	**82**	**83**	**340**	**0.09**	**32**	**91**	**89**	**90**	**379**	**0.25**	**94**	**80**	**76**	**77**
Nozzle 40	**1199**	**0.10**	**114**	**90**	**89**	**88**	**525**	**0.04**	**24**	**95**	**93**	**95**	**602**	**0.12**	**72**	**89**	**87**	**85**
P. 2 Bar																		
Nozzle 20	**381**	**0.17**	**64**	**85**	**83**	**83**	**169**	**0.19**	**32**	**82**	**80**	**80**	**195**	**0.27**	**53**	**78**	**74**	**76**
Nozzle 30	**827**	**0.16**	**128**	**85**	**84**	**82**	**382**	**0.13**	**51**	**86**	**85**	**86**	**417**	**0.20**	**82**	**83**	**80**	**76**
Nozzle 40	**1304**	**0.09**	**121**	**91**	**89**	**88**	**638**	**0.09**	**59**	**91**	**89**	**89**	**657**	**0.13**	**85**	**88**	**86**	**85**

M: Mean application [mm]
SD: Standard deviation
CV%: Coefficient of variation
CU_{HH}%: Heermann and Hein Modified Formula,
CU_C%: Christiansen Formula
DU%: Distribution uniformity
P: pressure

On average, the wetted diameter of the PWM system was 5% less than the wetted diameter of the uniform application under pressure 1 and 1.5 bar but in an application event under nozzle 40, it became less than 10%. Under 2 bar pressure, there was no difference in the wetted diameter between the two systems (Table 2). Furthermore, there was no significant difference in the wetted diameter in the heights between 1m and 1.5m even though the wetted diameters were slightly higher for the second one.

Table 2. The wetted diameters for nozzles 20, 30 and 40 under the specified operating pressures: 1. 1.5 and 2 bar.

pressure	**The Wetted Diameter m**	
	UA	**PWM**
P.1 Bar		
Nozzle 20	**10.5**	**10**
Nozzle 30	**10**	**9.8**
Nozzle 40	**10.6**	**9.5**
P.1.5 Bar		
Nozzle 20	**13.2**	**12.5**
Nozzle 30	**13.1**	**12.8**
Nozzle 40	**13.1**	**12.3**
P.2 Bar		
Nozzle 20	**12.9**	**12.9**
Nozzle 30	**13.2**	**13.1**
Nozzle 40	**13.2**	**13.3**

The sprinkler application patterns for each nozzle under each pressure are illustrated in Figure 2. The following were the research findings:

Figure 2. Water Distribution Patterns under different pressures: 1, 1.5 and 2 bar from top to bottom. On the left is the uniform application and in the right is the PWM. N: the nozzle type. (DC stands for the distance from the centre measured in decimeters).The nozzle is located in the centre at the point represented by the distance zero

Increasing the amount of applied water by the specified nozzles tended to improve the CU_C and CU_{HH} in both systems (PWM and BMS) under all operating pressures except at 1 bar. The uniformity coefficients (CU_C and CU_{HH}) tended to be higher with pressure 1.5, 2 bar than with pressure 1 bar. The CU_{HH} values were lower than the CU_C values. In general, the uniformity coefficients (CU_C and CU_{HH}) of the BMS were always lower than those of the uniform application and the PWM control systems.

In all the tests conducted, the distribution uniformity did not increase when the system operated at higher pressure: from 1.5 to 2 bar. The water distribution uniformity DU was improved in response to the increase in both the pressure and the nozzle orifice diameter except at lower pressure where it stayed constant. The DU also improved in relation to the increase in the mean water application depth of each nozzle. The CU values were always higher than the DU values. Nevertheless, the former values were more susceptible to the application rate variation.

The effect of the height was studied for the pressure of 1.5 bar. By comparing the effect of the nozzles head height of 1 m (table 1) with that of 1.5 m (table 2), it was found out that the uniformity (CU_C and CU_{HH}) were 89, 87 % for 1 meter height and the uniformity (CU_C and CU_{HH}) were 91, 90 % for 1.5 meter. The nozzle head height of 1.5 meter showed better results than the nozzle head height of 1 meter. As for nozzle 40, it appeared that there was not a big difference in uniformity because of the small distribution cycle for that nozzle under the pressure of 1.5. Table 3 illustrates the effect of the change in the nozzle head height from 1.0m to 1.5m on the CU_C%, CU_{HH}%, DU%, CV% and the Mean Application Depth. Figure 3 shows the application patterns of the three nozzles for the two heights 1.0m to 1.5m under the pressure of 1.5.

Table 3. The CU_C%, CU_{HH}%, DU%, CV% and the Mean Application Depth mm for sprinkler head height of 1.5m.

P. 1.5 Bar	Mmm	CV%	SD	CUc%	CUhh%	DU%
Nozzle 20	317	0,11	36	89	87	87
Nozzle 30	555	0,09	49	91	90	90
Nozzle 40	774	0,13	100	89	87	82

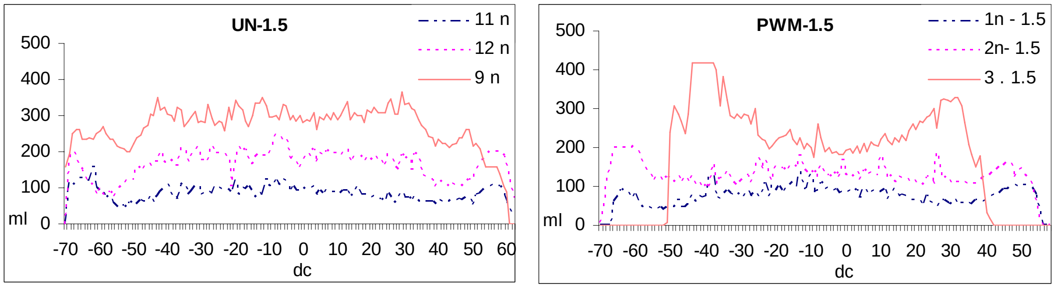

Figure 3. The height effect on the water distribution patterns for the three nozzles. The diagram on the left indicates the nozzle head height of 1 meter, the one on the right the nozzle head height of 1.5m.

As shown in Figure 4, the trend lines corresponded to the actual data of the DU% for each spraying system. The regression analysis using the R squared displayed in general high coefficient determination with the PWM at pressure 1.5 bar. That is probably due to the change in the water trajectory during the pulsing frequency. The R squared reading, on the other hand, was low, under 1 bar (Table 4).

The slope of the trend line gave negative values in all the experiments under 1 bar pressure while it gave positive values under higher pressures 1.5 and 2 bar. The mean square error (MSE) values from the regression line to the actual measured DU% were high for all experiments conducted under 1 bar pressure and were very low for all experiments conducted under 1.5 bar pressure.

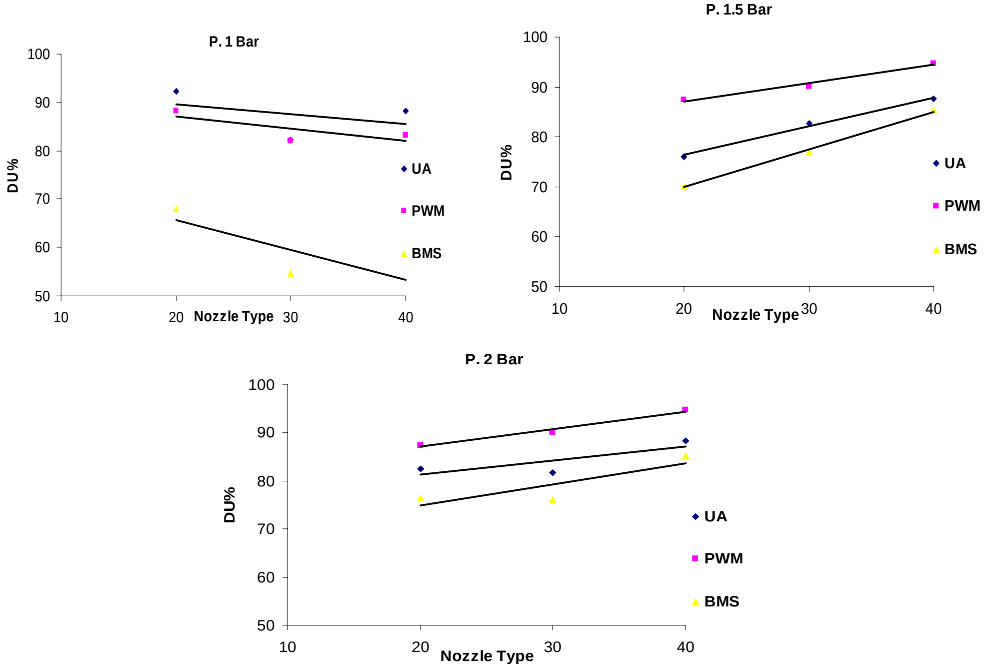

Figure 4. The regression line for the experiment conducted under 1, 1:5 and 2 bar pressure

Table 4. R-square values for all the experiments for 1m sprinkler head height

pressure	UA application	PWM application	BMS application
	R^2	R^2	R^2
1 Bar	**0.15**	**0.99**	**0.65**
1.5 Bar	**0.58**	**0.98**	**0.98**
2 Bar	**0.7**	**0.99**	**0.73**

4. DISCUSSION

An advantage of the PWM was that the application depth could be varied continuously. The processor allowed the user to adjust the pulsing frequency and the duty cycle to the desired application depth (Fraisse, *et al*, 1995a). As a result, the PWM system allowed the operator to adjust the water amount to the optimal irrigation depth whereas the BMS system was adjusted to perform only two irrigation patterns. The user had the option of turning the system on and off. In the PWM system, the increase in pressure and in nozzle orifices rendered the collected amount of water closer to the calculated one. (As half of the application) The mean water application increased with the increase in pressure. The PWM system achieved better uniformity with the operating pressure of 1.5 bar. It performed better than the uniform application under the same pressure and under the higher pressure 2 bar. It even performed better than its own performance under 2 bar.

Minimizing irrigation application via stopping half of the nozzles sequentially resulted in a huge deterioration in the water uniformity. The uniformity deteriorated from 95% under the uniform application to 75% under the BMS in nozzle 20, from 95% to 75% in nozzle 30 and from 95% to 75% in nozzle 40. The BMS system thus proved to be inefficient within 1 bar pressure. When the water application amount was standardized for the three systems, the distribution uniformity revealed very low values for the BMS system compared with those for the PWM in all tests. When the pressure increased in the BMS, the DU showed slight improvement compared to that of the PWM. The distribution uniformity should not be disturbed as a result of changing the application depth- the quantity of water (Fraisse *et al.* 1995b).

The Uniformity coefficients (CU_C and CU_{HH}) tended to improve with the increase in pressure from 1 to 1.5 bar. Improving the application uniformity was considered by Clark *et al.* (2003) and Pereira (1999) as one of the most important objectives realized by the operator. The evaporation and wind losses could be lower with the application of a lower pressure system than with that of a higher pressure system or a higher nozzle discharge; thus reducing the application efficiency (Clark *et al.*, 2003). Low sprinkler height under windy conditions had the advantage of minimizing the evaporation and wind drift potential losses. Tarjuelo. *et al*. (1999b) studied in detail the effect of the outdoor variables such as wind, evaporation and drift losses wind speed has a clear negative impact on the uniformity of water distribution.

For comparing and evaluating the different VRA irrigation systems, several mathematical models (Tarjuelo *et al.* 1999) were used to limit the uncertainty associated with the use of a single model. Different sampling standards used to specify the density of the sampling, the distance among the collectors, the number and size of the collectors displayed difference in the collectors' diameters. The DS/ NE ISO 11545 standard specified the minimum dimensions of the collectors as 120 mm height and the entrance diameter as the one that lies within the range of half to full height of the collector but not less than 60 mm (DS/EN ISO 11545, 2001) whereas the ASAE-Standards, (2003) specified the collector opening to be circular with a minimum diameter of 80 mm. Marek, *et al*, (1985) used two different collector types: a Separatory funnel and an Oil can with two different diameters: 90.2 mm 103mm. They noted the effect of using the different collector types on the mean depth which was 49.8 mm using the Separatory funnel and 53.7 mm using the Oil can. The coefficient of variation varied from 7.1 % to 5.5 % respectively.

For comparing and evaluating the different VRA systems, several statistical models were used to limit the uncertainty associated with the use of a single model. However, due to the lack of standard sampling techniques for comparing the irrigation systems, the same sampling methodology was used in all tests. The CV values showed high variation between the two controllers for all the tests. That might be due to the small width of the collected furrows. Narrowing water collector spacing resulted in a more accurate assessment of the wetted diameter. DeBoer (2002) used catch can spacing of 0.25m and obtained much accurate results than those attained by Sourell *et al.* (2003) who used 0.50m spacing. In the current study, the adjoining furrows were used to obtain accurate measurement of the applied water since they collected all the water sprayed by the nozzles. Thus the sampling error was reduced.

There was no interpolated data in producing the water application pattern curve or in the simulation. All the spatially water distributed by the sprinklers was used in the simulation process and in the performance calculations. The wetted diameter was experimentally determined by measuring the distance to the last cylinder receiving the sprayed water. Cylinders receiving less than what was equivalent to 10% of the mean water application depth were not included in the calculations.

5. CONCLUSION

A comparative study of two VRA systems: the PWM and BMS was performed. The two systems were contrasted with the uniform application system under the same conditions of low operating pressure and then evaluated by applying the CU_C%, CU_{HH}%, DU%, CV%, SD and the Mean Application Depth. Evaluation indicated that the behaviour of both VRA systems was drastically different under low pressure 1 bar. Generally, in all the application systems under study, the smaller the throw radius of the nozzle, the lower the coefficient of uniformity and the distribution uniformity percentages.

By comparing several operating pressures, it was observed that there was a great difference in uniformity between the pressures selected. Pressure 1.5 bar with the PWM was found to be the lowest pressure that gave the optimal results. Pressure 2 bar with the BMS yielded better results than 1 and 1.5 bar. However, the PWM proved to have higher correlation with the uniform application than with the BMS. The PWM system demonstrated a higher capability in responding to the changes in the amount of water required for different irrigation depths than the BMS system which had only one option. The results obtained from this test could benefit both the engineers and the operators when selecting the application system, the type of sprinklers and the operating pressure that could achieve high water distribution uniformity.

6. **ACKNOWLEDGEMENT**

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