Analysis of nozzle spray distribution for different nozzle height and pressure

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Abstract: A patternator was designed and constructed with the aim of field sprayers pattern testing and consequently, application of more accurate weed control, reducing environmental and economic costs associated with weed control. The patternator was tested at six spray heights (50, 60, 70, 80, 90 and 100 cm) for each of the three levels of system pressure (1.0, 2.0 and 3.0 bar). All measurements were performed spraying water with a temperature of 20^{o}C in the laboratory. Environmental conditions are kept constant at a temperature of 48^{o}C, relative humidity of 51% and wind speed 3 m s^{-1}. The spray width (cm), standard deviation and coefficient of variation (CV) of spray distribution patterns were obtained from patternator experiments at various nozzle heights and pressures. The result reveals the spray width was proportional to nozzle height, while CV and standard deviation values were not significantly correlated with nozzle height for other pressures. Increasing spray width occurred for all boom heights and pressures. The best distribution uniformity occurred at the height nozzle 100 cm for 3.0 bar pressure.

Keywords: sprayer, pattern, horizontal patternator, weed control, uniformity, costs

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1 Introduction

The purpose of applying agricultural chemicals is to provide nutrients for plant growth and to control weeds, insects and other crop pests, and plant diseases. Proper application of agricultural chemicals is crucial in successful modern agriculture. Agricultural chemicals, over the years, have become more sophisticated but also more expensive, so good methods avoid over-application (Srivastava et al., 1993). The weeds can be competitive in the early stages of the crop growth and if uncontrolled, can cause more yield loss and time consuming in their removal. Hence they must be adequately controlled in order to cultivate crops profitably. Worldwide crop losses from all pests have been estimated to exceed 140 billion U.S. dollars annually (Aaron, 1994). Chemical application has been very successful in weed control but must be applied in rationed proportions and spray characteristics. Specialized equipment is thus essential. In fact, chemical application is the only fully mechanized farming operation. Developing spraying machines entails determining the nozzle characteristics as well as the pump discharge in order to ensure that desired application rate and coverage are not exceeded. Nozzle characteristics are first inferred from the spray pattern. Spray pattern refers to the regular form of the spray from the showerhead or nozzle, i.e. drenching rain, fine mist,

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sharp spray and massaging swirl spray patterns. Patternation is the measurement of uniformity and symmetry of the liquid distribution in a spray. Patternator is the instrument used to measure the spray distribution in a spray. Patternation can supply a quantitative measurement for the spray. The quantitative analysis of spray patterns is very important for nozzle design, selection and quality control, because the spray angle, the uniformity and the symmetry of the spray patterns are decisive parameters in practical applications (Cao, 2001).

The motion of a spray boom is a major source of variation in the distribution pattern of a sprayer. The possible effect of these movements on the uniformity of spray distribution is predicted as part of an overall strategy to improve the design of sprayer booms (Iyer and Wills, 1978).

Krishnan et al. (1988) developed a technique for measuring spray pattern displacement in agricultural nozzles. Wang et al. (1995) carried out an experimental analysis of spray distribution pattern uniformity for Agricultural spray nozzles. Gil et al. (2013) designed and developed two simple vertical patternators to evaluate their efficiency in terms of spray recovery, symmetry and repeatability. They found that the ability of the two prototypes to measure the vertical distribution of liquid, as well as the important similarities between the liquid distribution profiles obtained with both patternators in comparison to the reference one (Gil et al., 2013). Hassen et al. (2013) fabricated a spray patternator for the selection of a suitable nozzle to have uniform distribution of the spray liquid.

Mechanical application of agrochemical is the commonest method of pest control in modern crop protection practices. This is a method in which the controlling chemical agents -either in the form of droplets or dusts - are carried to their target plant(s) or soil surface(s). Thus, the aim of this research was to design, construction and evaluation of a patternator, inexpensive and practical tools for measuring spray pattern, furthermore we determine the effect of boom height and nozzle pressure on spray distribution pattern.

2 Materials and methods

2.1 Description of the horizontal patternator

A spray pattern analyzing system or patternator is a device used to empirically determine the distribution (scatter or spread) of fluid from one or more spray nozzles. When one spray nozzle is used, there is a relatively even distribution of fluid on the spray surface. However, if two spray nozzles are used together such that there is an area of overlap, there will be a section of higher fluid concentration. This area of excess fluid is undesired because it results in increased costs and, in some cases, may be harmful to the environment. Therefore, it is desirable to locate an optimal spacing between the nozzles and a certain height from target so that the spray distribution is as uniform as possible and the overlap regions do not result in areas of high concentration, minimizing excess fluid. A laboratory patternator was designed and developed at the Department of Mechanical Engineering of Biosystems workshop, University of Jiroft (Figure 1).

Figure 1 The spray patternator

This device consists of a table inclined at 0, 10 and 15 degree divided into a number of grooved channels. The table was fabricated of galvanized metal sheets and used to collect spray liquid (water) from the tested nozzles. The table is made into sixty (5 cm wide × 5 cm deep) U-shaped channels or gutters. The width of the channels is dependent upon the desired resolution of the spray distribution. Obviously, smaller channel width will produce higher resolution of the spray distribution. This patternator table is supported by a chassis of dimensions 300 cm×150 cm. The tube rack is also supported by this chassis fixed 40 cm above the ground.

The spray nozzles are supported at regulated heights above the table. The nozzle location above the table will also affect the distribution of the spray so it is important to test the nozzles at different heights. When the fluid reaches the table, it will be separated into the different channels and flow down the incline. A tube is kept directly under each channel on the sloping side of the table, spray liquid falling on the own graduated cylinder through the tube. The person running the experiment must record the height of the water in each cylinder by reading the measurement in each graduated cylinder (Figure 2).

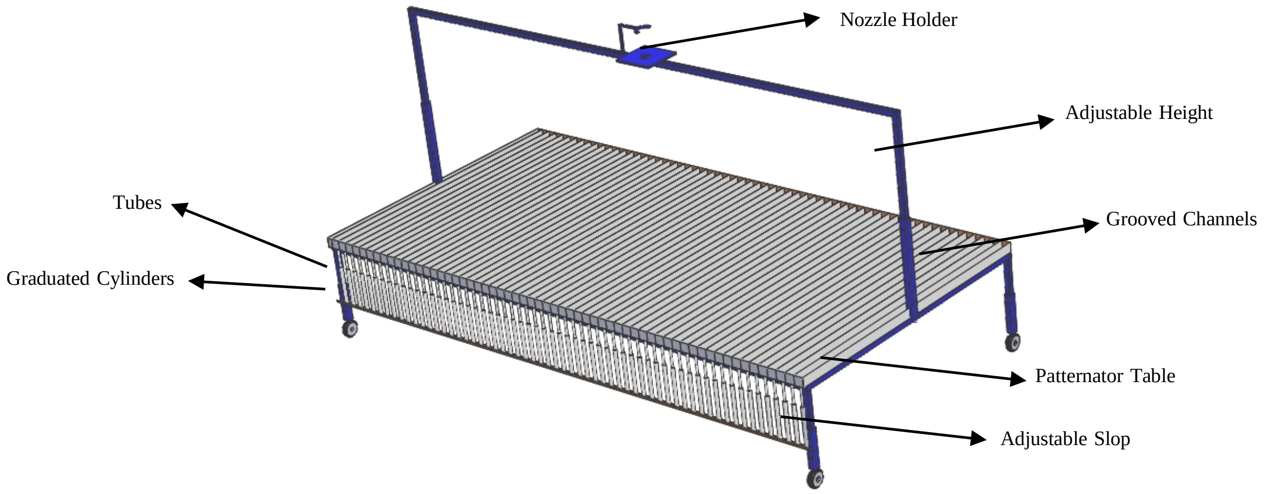

Figure 2 3D model of the equipment

2.2 Test procedure

Spray distribution pattern determination was carried out on this patternator. The sprayer was mounted on a frame above the patternator at variable heights of up to 50 cm. The boom type sprayer model of POWER SPRAYER 22.28.30 (Golpash Sanat Company) was selected for this study.

Tests were carried for heights of 50, 60, 70, 80, 90 and 100 cm at three levels of system pressure (1.0, 2.0 and 3.0 bar). Spray liquid was tap water and water discharged from the nozzle at different pressures. Static single nozzle was mounted on different heights of up 50 cm above the spray table. Data of average wind speed, air temperature and relative humidity during field experiments were recorded by applying Extech EN300 5-in-1 Environmental Meter at 3.0 m s^{-1}, 48^{o}C and 51%, respectively. The Extech EN300 is a 5-in-1 environmental meter that allows users to test relative humidity, temperature, wind speed, light and sound levels all with one compact instrument. The Extech EN300 environmental meter has a built-in vane anemometer for making quick and accurate wind speed readings. The high precision humidity sensor has a rapid response time for effortless readings of relative humidity. In front of the table, a set of graduated cylinders was used to collect the liquid from each channel. During the tests, the spray table was inclined 6° from the horizontal plane. A slight slope was maintained in the corrugated table surface to completely drain the channels into the graduated cylinder. When all the graduated cylinders had been measured, they were emptied and dried. The patternator was also dried to avoid interference with the next measurement caused by tap water that might possibly have remained in the channels. The sprayer was operated for 10 seconds in each situation to be able to obtain a measurable amount of spray from the collecting tubes and this was replicated three times. The weighting method was used to determine the water collected during 10 seconds by using a precision balance. Results of spray volume distribution pattern were presented as (mL) at single nozzle different pressures and heights. All measurements were performed spraying tap water with a temperature of 20^{o}C in the laboratory. As the tap water kept at about 20^{o}C and temperature in the room was also about 20^{o}C, any temperature compensations needed were small. Before the measurements were started, the tap water was allowed to flow a while until the water temperature had stabilized.

2.3 Statistical analysis

The data from spray tests were collected to analyze the variance using a mathematical model for calculating the standard deviation and coefficient of variation. The calculations made use of the statistical package of applications Microsoft Excel. The Coefficient of Variation is expressed as the ratio of standard deviation and mean. It is often abbreviated as CV. Coefficient of variation is the measure of variability of the data. When the value of coefficient of variation is higher, it means that the data has high variability and less stability. When the value of coefficient of variation is lower, it means the data has less variability and high stability. Mathematically, the coefficient of variation is the estimated standard deviation (an absolute Measure). The formula for coefficient of variation is given as:

$$CV = \frac{SD}{X} \times 100 \quad (1)$$

Where: *CV* presents the coefficient of variation %, *SD* standard deviation and *X* the mean data.

3 Results and discussion

The initial raw data of the spray liquid (water) collected in the graduated cylinders for each replication was utilized to illustrate the general spray distribution characteristics. The Spray Width (cm), Standard Deviation and Coefficient of Variation (CV) of spray distribution patterns obtained from Patternator experiments at various nozzle heights and pressures are summarized in Table 1.

The CV of spray distribution ranged from 40% to 60%, 36% to 65% and from 34% to 59% for 1.0, 2.0 and 3.0 bar pressures, respectively. The average of CV values at 3.0 bar pressure was lower than other pressures therefore this pressure had better distribution uniformity.

It can be seen in Table 1 that the lowest CV of 34%, hence best distribution uniformity, occurred at the height nozzle 100 cm for 3.0 bar pressure. From the above table the highest coefficient of variation of 65% was obtained at the height of 60 cm for 1.0 bar pressure, while the coefficient of variation of height 100 cm (34%) is the least obtained. The nozzle height was found to greatly influence the CV, which was in agreement with the findings reported by El-Khawaga (El-Khawaga, 2004).

Combellack (1982) reported that there could be slight variability of the uniformity of the spray volume distribution on the field as a result of both horizontal and vertical boom instability resulting from the nature of the field surface and also to a lesser extent the meteorological conditions. Generally the values of the coefficient of variation obtained from the experiment are high as compare to the previous values from 34.6%, this is as a results of the improvement on the peristaltic pumps, incorporation of operator's seat, and sprayer tank (Abdul-Fattah, 1997).

Table 1 Coefficient of Variation for Patterns obtained from Different Nozzle Height at Various Pressure

Nozzle Height (cm)	Pressure, 1.0 bar			Pressure, 2.0 bar			Pressure, 3.0 bar		
	Spray Width (cm)	Standard Deviation (cm)	CV (%)	Spray Width (cm)	Standard Deviation (cm)	CV (%)	Spray Width (cm)	Standard Deviation (cm)	CV (%)
50	65	13.30	40	85	9.50	54	90	12.74	43
60	90	11.79	50	105	10.94	65	110	8.41	38
70	100	9.26	60	110	9.71	36	120	8.75	41
80	130	4.93	44	150	4.70	44	125	9.73	55

90	140	5.35	41	165	12.28	49	145	8.49	59
100	165	4.46	46	175	6.60	39	165	3.84	34

The uniformity of spray application influences the amount of chemical or biological crop protection products delivered to individual plants, rows, or field areas. Motion of the spray boom may affect spray uniformity. For instance, the application rate at a plant depends on the nozzle output, longitudinal boom velocity, and on the spray overlap determined by the instantaneous boom height. Uniformity of droplet distribution is the most important indicator of the nozzle performance.

Information in above table reveals that the spray width was proportional to nozzle height, while CV and standard deviation values were not significantly correlated with nozzle height for other pressures. We concluded that the CV was not a function of nozzle height changes. Mawer and Miller (1989) concluded that 2 degrees increase in roll angle of the boom caused increasing coefficient of variation (CV) of spray deposit of an 18-m boom at the optimum height which gives the most even distribution for particular nozzles and nozzle spacing. They concluded that the CV of spray deposit was a function of nozzle height changes. Increasing boom height from 50 to 100 cm increased spray width at 2.0 pressure from 85 to 175 cm more than the same nozzle at 1.0 and 3.0 pressure. Increasing of boom height tend to give a high spray width (Mawer and Miller 1989).

The spray volume distribution was carefully studied in the laboratory in order to determine the height and pressure that gives the best even distribution of the spray. The average values of liquid disposal from each patternator channel at different heights and pressures were plotted against the graduated cylinder number as shown in Figures 3, 4 and 5. It can be seen from Figure 3 that the spray liquid at 50 cm nozzle height was stretched over only 13 (from 25 to 38) graduated cylinders. As the nozzle height increased to 60 cm, the discharge out of the nozzles was distributed on larger area (stretched over 41 graduated cylinder, from 24 to 41) and this phenomenon was occurred with increase of nozzle height. For example, the spray liquid at 100 cm nozzle height was stretched over 38 (from 17 to 55) graduated cylinders producing smoother curves compared to those produced at other heights of nozzle. These finding from Figure 3 was coincided with Figure 4 and Figure 5.

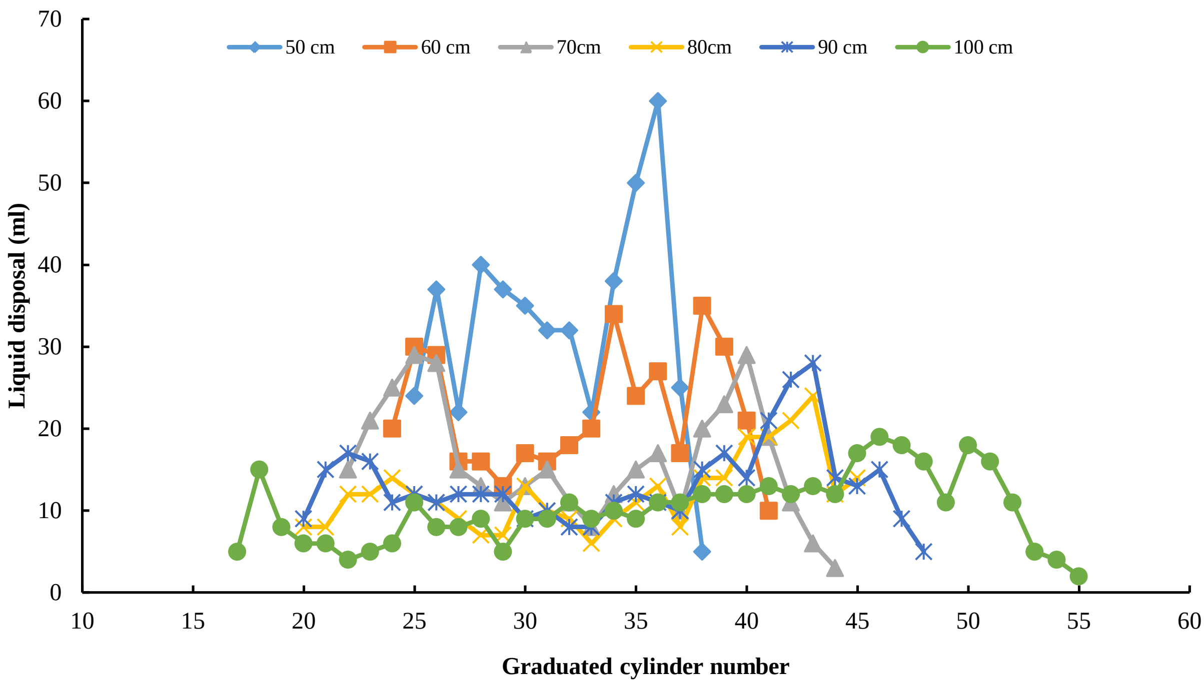

Figure 3 Spray volume distribution pattern of the patternator at 1.0 bar pressure and different heights

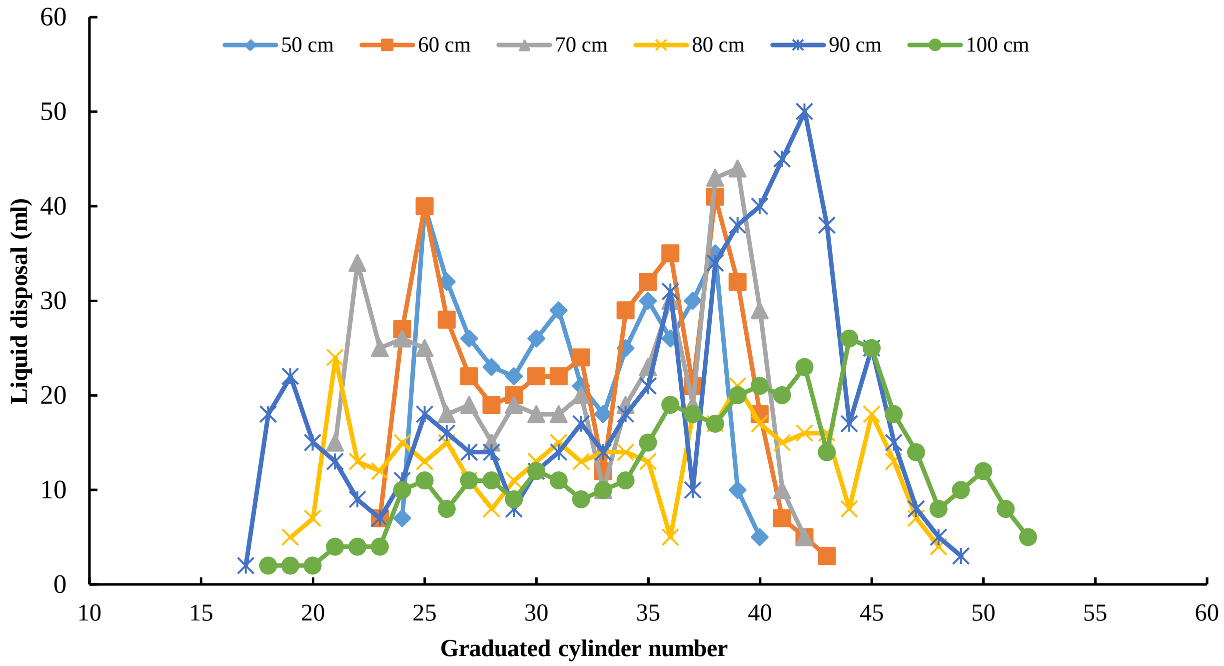

Figure 4 Spray volume distribution pattern of the patternator at 2.0 bar pressure and different heights

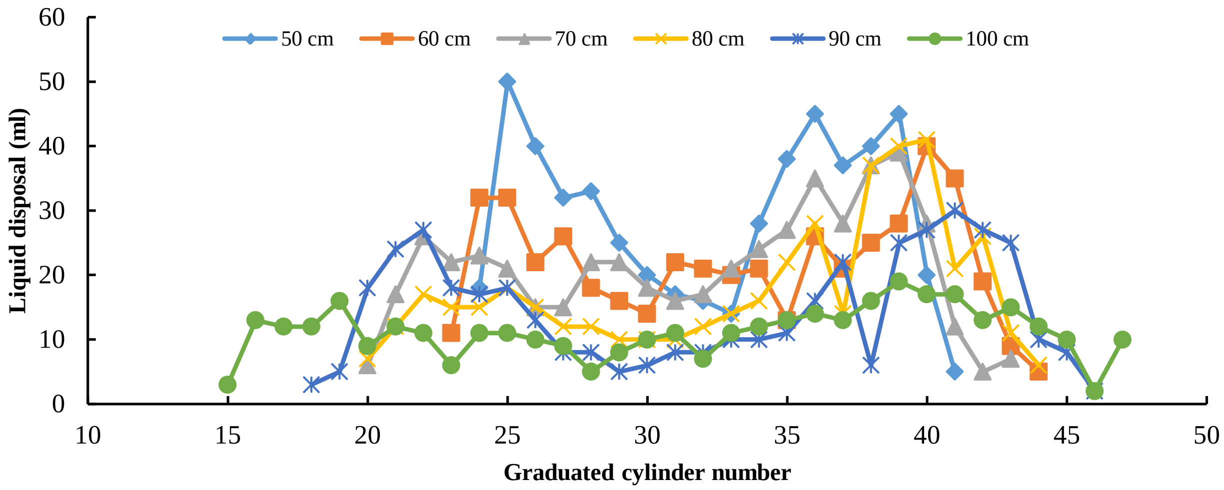

Figure 5 Spray volume distribution pattern of the patternator at 3.0 bar pressure and different heights

Among the Figures 3, 4 and 5, the most liquid disposal value (weight of water collected directly under graduated cylinders) was found for the spray with 50 cm nozzle height and 1.0 bar pressure (Figure 3) that reached 60 mL related to graduated cylinder No. 36. This value was obtained of Figure 4 amount 50 mL related to graduated cylinder No. 42 with 90 cm nozzle height and about Figure 5 was 50 mL related to graduate cylinder No. 25 with 50 cm nozzle height. Among the spray volume distribution patterns shown in Figure 2, the 50 cm height of nozzle had more abrupt rise and fall than the others. This finding was agreed with Figure 4 but was different with Figure 3. This result showed that the 2.0 bar pressure nozzle provide spray volumetric distribution better than the others pressures at 50 cm nozzle height. Higher than recommended pressures increase the delivery rate, reduce the droplet size, and may distort the spray pattern (similar Figure 4). This can result in excess spray drift and uneven coverage. Low pressures reduce the spray delivery rate, and the spray material may not form a full width spray pattern (similar Figure 2) unless the nozzles are designed to operate at lower pressures. The resulting distribution is dependent on the nozzle height and pressure, however when comparing results from Figures 3, 4 and 5, one should bear in mind that the distribution curves of the nozzle output at 3.0 bar pressure were approximately smooth especially at 100 cm nozzle height was almost flat as depicted in Figure 4.

4 Conclusion

A spray patternator was fabricated and evaluated for the purpose of determining the spray distribution in sprayers. A spray analysis system or patternator measurement would probably be sufficient to accurately evaluate the static spray volumetric distribution. From laboratory experiments results, it was noted that the height nozzle 100 cm at 3.0 bar pressure gave the best spray uniformity with the minimum coefficient of variation. The 3.0 bar pressure nozzle provide spray volumetric distribution better than 1.0 and 2.0 bar pressures nozzle because they reduce size of droplets. Increasing spray width occurred for all boom heights and pressures.

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