Band sprayer using movable nozzles in comparison with broadcast spraying for reducing herbicide use in maize (*Zea mays* L.)

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Abstract: In order to examine the reduction of herbicide consumption, the effect of band sprayer type was studied at two levels, band sprayer using a movable nozzle and band sprayer using a fixed nozzle. Additionally, the height of the even flat fan nozzle 8002 relative to the ridge surface was tested at three levels of 20, 30, and 40 cm. This was conducted in a factorial experiment based on a randomized complete block design with three replications. The broadcast spraying treatment was also considered as the control treatment, and compared with a movable nozzle at a height of 30 cm using the Student's t-test. The flow rate of each nozzle in both band sprayer types under constant pressure (3 bar), the band width in band sprayers, weed control index, and crop yield were measured and analysed. The result showed that the width of the band on the ridge decreased from the center nozzle to the end of the boom. The highest maize grain yield was achieved in case of the band spraying treatment using a movable nozzle at a boom height of 30 cm with 15.17 t ha^{-1}, showing non-significant difference to the broadcast spraying method ($p > 0.05$). This treatment had a mean weed count of 4.2. Additionally, a reduction in the consumption of acetochlor herbicide by 46.7% was achieved in this treatment, making it recommendable.

Keywords: adjustable nozzle, nozzle height, spray band width, weed, yield.

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1 Introduction

Maize is the world's most important economic crop after rice and wheat (FAO, 2023). Maize is also one of the most popular cereals, adapting to a wide range of climatic and soil conditions. Therefore, it is expected to be introduced as the most widely cultivated and commercially important crop in the next 10 years (Partal and Paraschivu, 2020; Dragomir et al., 2022; Lamichhane et al., 2023).

The rapid development of herbicide resistance has led farmers to use methods other than chemical methods to control weeds (Andert and Ziesemer, 2022). One method for controlling weeds is the use of herbicides. Improper application of herbicides can lead to environmental contamination (Loddo et al., 2020). Chemical weed control is widely used, but it severely compromises crop health and the environment (Chandel et al., 2021). Some researchers believe that the main problem is controlling weeds that are present in the main crop

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row (Raja et al., 2020).

In addition to weeds between rows, weeds in the rows also reduce yield by about 18%-76%, and therefore their control is essential (Alba et al., 2020). Therefore, to achieve optimal yield and high-quality crops, controlling weeds between and within the crop rows is particular importance (Gerhards et al., 2020).

One approach to reduce or limit the use of herbicides is band spraying. Band spraying was introduced as a precise spraying method within the crop row (Osuch et al., 2020).

The evaluation of band spraying combined with mechanical weed control (integrated control) in the maize ridge-tillage system demonstrated that this control method could be more effective in weed management. Weed control using integrated management in the maize ridge-tillage system was reported at 85.5%. According to the faster growth of maize in this tillage system and the warmer conditions on the ridge, maize outcompeted the weeds, and the effect of band spraying on the ridges was more pronounced (Alagbo et al., 2022). The reduction in herbicide consumption by 50%-70% is one of the major reasons for the use of band spraying in maize and sugar beet cultivation (Kunz et al., 2018).

In a study, herbicide use alone and a combination of band spraying and cultivator were used in maize and soybeans from 2020 to 2024. The results of the experiment showed that the combined treatments reduced herbicide use by 24% to 60% compared to the use of herbicide on the total area. Also, weed control with a combined chemical and mechanical method did not reduce maize and soybean yields compared to the use of herbicide (Gerhards et al, 2024).

In three experiments, herbicides were initially applied post-emergence using band spraying in 50% of the field area in maize. Subsequently, the field was treated with pre-emergence herbicides using band spraying in 33% of the area. The broadcast spraying method (100% area) was also considered as a control. Weeds between the planting rows were controlled with a cultivator. The results showed that there was no significant difference between the broadcast and band spraying treatments in terms of yield in maize. The use of band spraying reduced the amount of herbicide (Loddo et al., 2020).

Adjusting the nozzle height and the distance between nozzles according to the plant growth stages is crucial for the efficiency of band spraying. In a study on weed control in carrots, the nozzle spacing and height in band spraying were set in such a way that they perfectly matched the width of the ridge. In this case, a reduction in herbicide usage by up to 80% and a 2.7 to 3.7 times increase in the efficiency of band spraying compared to broadcast spraying were observed (Lamare et al., 2022).

Spray pressure affects the width of the band created in band spraying. The results of a study showed that flat fan nozzles, when operated at a pressure of 2 bar, did not exhibit a significant difference in the width of the band created by the nozzle. However, when the pressure was increased to 3 bar, the band width increased, and a significant difference between them was observed (Hassen and Sidik, 2019). An issue related to band spraying is the need to maintain precise nozzle positioning relative to the crop rows during spraying. This issue is especially critical when herbicide application is done separately from crop planting, such as in pre-emergence applications. Therefore, it is necessary to precisely adjust the nozzle position on the boom to align with the center of the crop row. The cultivator blades must eliminate weeds between the rows up to the sprayed band on the ridge (Gursoy and Ozaslan, 2021).

The high costs of spot-spraying machines have limited the widespread use of this method. Therefore, given the advantages of band spraying, there is a need for systems that are easy to use, cost-effective, and capable of spraying narrow bands on the crop ridge (Loddo et al., 2020).

A meta-analysis of research results showed that the success of band spraying depends on the width of the spray band, the use of mechanical methods with cultivators between the rows, and the timing of herbicide application. Considering these factors, band spraying can be a suitable alternative to broadcast spraying without reducing crop yield (Ozaslan et al., 2024).

Despite the positive results of band spraying, this method has not been widely adopted in practice. The lack of available machinery for band spraying is one of the main limitations of this method (Loddo et al., 2020). In Iran, there are no dedicated booms for band spraying. In some cases, nozzle angles are adjusted to achieve the appropriate ridge width for band spraying, which does not provide sufficient accuracy. The aim of this study was to evaluate the reduction in herbicide consumption through band spraying compared to broadcast spraying in weed control for maize fields by developing a new band sprayer with movable nozzles and the capability for horizontal and vertical adjustment above the ridge of maize crop.

2 Materials and methods

2.1 Site specifications

This study was conducted for two years (2022-2023) at the Agricultural Research Station in Darab city, Fars province, Iran. The latitude and longitude of Darab city is 28° 47 ' N and 57° 28 ' E, with an elevation of 1120 m above sea level. Some soil characteristics of experiments are shown in Table 1.

Table 1 Some soil characteristics of experiments

Characteristic	Value
Soil reaction (pH)	8.1
Electrical conductivity (Ec) (dS m^{-1})	0.57
Organic carbon (OC%)	0.5
Available P (mg kg^{-1})	3.2
Available K (mg kg^{-1})	188
Silt%	42
Clay%	19.3
Sand%	38.7
Soil texture	Loamy

2.2 Band sprayers and experimental treatments

In this experiment, two types of tractor-mounted band sprayers were evaluated and assessed in maize fields. The experimental treatments included two levels of band sprayer types: band sprayer with a movable nozzle (S_1) and band sprayer with a fixed nozzle (S_2). The nozzle heights were above the ridge surface at three levels: 20 cm (H_1), 30 cm (H_2), and 40 cm (H_3). The type of nozzle used in band and broadcast spraying were 8002 even flat fan nozzle and XR 8002. The broadcast spraying treatment was also considered as a control treatment and was compared with the band spraying treatment using a Student's t-test.

Each experimental plot was 20 m long, with 6 planting rows spaced 75 cm apart, and the plant spacing was 20 cm. A 2-meter distance was maintained between treatments. The sowing operation was carried out using hybrid maize seeds (704) at a rate of 25 kg ha^{-1} with a pneumatic row planter. Fertilizer application (urea, 425 kg ha^{-1}), was performed in three stages: one-third at planting and the remaining two-thirds at two additional stages (stem elongation and flowering). Phosphorus (triple superphosphate, 220 kg ha^{-1}) and potassium (potassium sulfate, 170 kg ha^{-1}) fertilizers were applied before planting. For spraying operations in the experiments, acetochlor herbicide (4 L ha^{-1}) were used. This herbicide is selective, pre-emergence and pre-plant.

The band sprayer boom with a movable nozzle (S_1) consists of a metal angle, onto which six nozzles with their corresponding pipes were installed. The six nozzles were independently fed by the sprayer pump through their respective tubes. The horizontal movement of the nozzles is achieved by a sliding clamp. The vertical movement of the nozzles was controlled by a screw, which securely held the nozzle tube in place when tightened. The flow of herbicide in each nozzle tube could be controlled and turned on or off using a control valve. The sprayer boom was connected to the sprayer chassis by two short arms.

The pesticide solution, after passing through the sprayer tank and filter, reached the piston pump. After being pressurized, it was transferred through a central pipe to individual hoses leading to each of the 8002 even flat fan nozzles, where it was dispersed according to the spray pattern. The advantage of this type of band sprayer boom over conventional booms is the ability for both horizontal and vertical movement of the nozzles, which is the fundamental operation of band spraying. Other parts of the sprayer, including the chassis, tank, pump, regulator, and pressure gauge, remained unchanged. In Figure 1, the band sprayer boom with movable nozzles and nozzle numbers from the right side of the tractor wheel is shown. Thus, with this type of boom, band spraying can be applied to various row crops (in this study, maize with nozzle spacing of 75 cm).

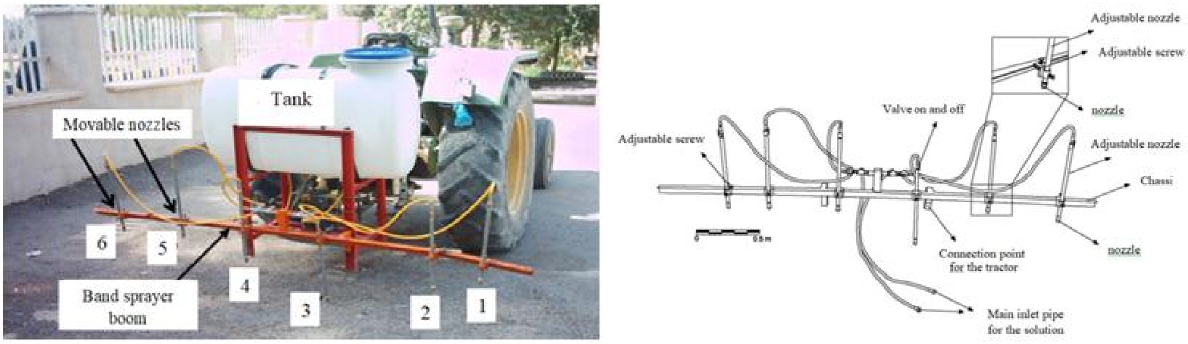

Figure 1 Band sprayer boom with movable nozzles

In the band sprayer boom with fixed nozzles (S_2), a conventional sprayer boom was used, and for band spraying, 6 fixed nozzles were mounted on the boom with a spacing of 75 cm. The height of the nozzles was adjusted by raising and lowering the boom on the sprayer chassis at distances of 20, 30, and 40 cm. The band sprayer boom with fixed nozzles and the nozzle numbers are shown in Figure 2. Mechanical operations between planting rows (in the furrows) were carried out using a sweep cultivator.

Figure 2 Band sprayer boom with fixed nozzles

2.3 Measurements

2.3.1 Flow rate of the nozzles

In this study, the flow rate in both band spraying and broadcast spraying systems was measured at 3 bar pressure. The feeding system of the spray from the tank to the nozzles differed in the two types of sprayers. Therefore, in both band sprayers and broadcast sprayers, the flow rate of each nozzle was individually measured using a graduated cylinder, with three repetitions, and compared (Hassen and Sidik, 2019; Smith et al., 1994).

2.3.2 Measurement of band dimensions in band spraying

The nozzle height of the sprayer is directly related to the width of the spray band on the ridge surface. For both types of booms, the width of the bands created on the ground was measured in three repetitions at nozzle heights of 20, 30, and 40 cm. The mean of these measurements was considered as the band width at the specified nozzle height.

2.3.3 Herbicide percentage effect

The acetochlor herbicide was used before the weed germination. At this time, no weeds were present in the field. After spraying, the mean number of germinated weeds was recorded in experimental plots. The mean number of weeds in the control plot was also counted (plot without weed control). A 1-m^2 quadrat was used to count weeds. The herbicide percentage effect was calculated using the following

Formula (Alptekin et al., 2023):

Herbicide percentage effect=[(Number of weeds in control - Number of weeds in treatments)/ Number of weeds in control] × 100

2.3.4 Maize grain yield

At the end of the season, after removing one meter from the top and bottom of each plot and two border rows, the maize grain yield was determined by harvesting the ears from the two central rows of each plot. After separating the grains from the cobs, the grain yield of each treatment was calculated on basis of 14% moisture content (d.b.).

2.4 Statistical analysis

A factorial experiment was conducted in a randomized complete block design with three replications, and Duncan's multiple range tests was used to compare the treatments means.

3 Results and discussion

3.1 Comparison of the mean flow rate between boom with **movable** and fixed nozzle

Table 2 presents a comparison of the mean flow rate between the boom with a movable nozzle and a fixed nozzle, with a 75 cm distance pressure across three repetitions, conducted for the purpose of band spraying.

Table 2 Comparison of the mean flow rate of boom with movable nozzles

Flow rate (mL min^{-1}) (3 bar)	Nozzle number from the right side of the tractor wheel
780 ^{b}	1
847 ^{a}	2
810 ^{a}	3
798 ^{a}	4
834 ^{a}	5
789 ^{b}	6

Note: The means shown in each column with common letters do not have a significant difference at 0.05 level (p = 5%) (DMRT)

Table 3 Comparison of the mean flow rate of boom with fixed nozzles

Flow rate (mL min^{-1}) (3 bar)	Nozzle number from the right side of the tractor wheel
768 ^{c}	1
781 ^{b}	2
840 ^{a}	3
849 ^{a}	4
771 ^{b}	5
762 ^{c}	6

Note: The means shown in each column with common letters do not have a significant difference at 0.05 level (p = 5%) (DMRT)

In this table, there is a significant difference at a given pressure between the nozzles at the beginning and end of the boom and the nozzles in the middle of the boom. Nozzles 2, 3, 4, and 5, with flow rates of 847, 810, 798, and 834 mL min^{-1}, respectively, show no significant differences among themselves and are classified within the same statistical group ($p > 0.05$).

According to Figure 1, the separate pipes connected to nozzles 1, 2, 5, and 6 are the first nozzles receiving the herbicide solution under pressure. The two middle nozzles (nozzles 3 and 4) receive the herbicide solution after nozzles 1, 2, 5, and 6. As a result, their flow rates slightly decrease due to a minor pressure drop. In nozzles 1 and 2, as well as nozzles 5 and 6, despite receiving the pesticide solution from the same point on the sprayer boom, the length of the pipe determines the applied pressure and, consequently, the nozzle's flow rate. The lowest flow rates were observed in nozzles 1 and 6, with values of 780 and 789 mL min^{-1}, respectively, indicating a pressure drop in these nozzles.

In the boom with fixed nozzles and a 75 cm spacing, two separate pipes are designed to supply the high-pressure herbicide solution to the left and right sides of the boom. In this type of boom, the nozzles in the middle (nozzles 3 and 4), due to their proximity to the sprayer pump and receiving higher pressure, exhibit higher outputs of 840 and 849 mL min^{-1}, respectively, showing significant differences compared to the other nozzles ($p < 0.05$).

In the band spraying boom with fixed nozzles, the output of the nozzles decreases from the center to the ends of the boom, which is due to the pressure drop along the boom. According to Table 3, the lowest nozzle outputs were observed in nozzles 1 and 6, with values of 768 and 762 mL min^{-1}, respectively.

The research conducted by Balsari et al. (2017) at different nozzle heights and using the 11004 nozzle demonstrated that the volume of spray collected in a graduated cylinder varied across 10 adjacent nozzles under a constant pump pressure. It was observed that adjacent nozzles had approximately the same flow rate, while nozzles farther apart exhibited differences in flow rate.

Another study conducted on six sprayers and their nozzle outputs revealed that the minimum and maximum coefficients of variation (from 19% to 43%) under constant pump pressure, depending on the boom length. This indicates the impact of pressure variation along the boom and its influence on nozzle flow rate (Nation, 1982).

3.2 Comparison of flow rate uniformity along the boom with fixed and movable nozzles

The comparison of the mean flow rate of 8002 even flat fan nozzles, as shown in Table 4, indicates that in the band spraying boom with movable nozzles, the nozzle output and coefficient of variation are 809.67 mL min^{-1} and 2.95%, respectively.

Considering the coefficient of variation in the two types of band sprayers (with movable and fixed nozzles) and the differences in nozzle supply along the boom, the uniformity of nozzle output in the band sprayer with movable nozzles is higher. Previous studies have demonstrated that the uniform volumetric distribution of the output herbicide solution is one of the key performance indicators for nozzles and a critical requirement for effective band spraying (Hassen and Sidik, 2019).

Table 4 Comparison of mean flow rate, standard deviation and coefficient of variation in band sprayers with fixed and movable nozzle

CV (%)	Sd (mL min^{-1})	Mean flow rate (mL min^{-1})	Band sprayer
2.95	23.91	809.67	Movable nozzle
4.45	35.40	795.25	Fixed nozzle

3.3 Band width created on the ridge surface by each nozzle at different heights of the movable nozzle

According to Figure 3, the band formed on the ridge surface by the spray from each nozzle has a direct relationship with the nozzle height. In band spraying, deviations exist between the theoretically calculated band width and the actual measured width (Jensen and Lund, 2006).

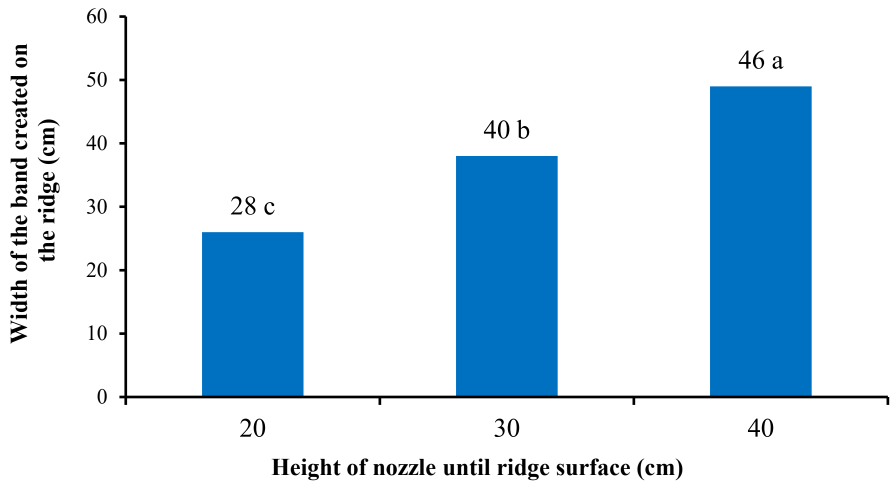

Figure 3 The mean width of the band created on the ridge at different heights of movable nozzle

The means shown in each column with common letters do not have a significant difference at 0.05 level (p = 5%) (DMRT).

With an increase in nozzle height, the width of the spray band on the ridge surface increases. The band width, considering the movements of the sprayer boom and the soil surface condition, is larger than the nozzle height setting (20, 30, and 40 cm). The largest band width formed on the ridge surface was 46 cm, achieved with a nozzle height of 40 cm. This band width showed a significant difference compared to the two widths of 40 and 28 cm on the ridge ($p < 0.05$).

As shown in Table 5, at a constant nozzle height (30 cm), despite the varying band widths on the ridge surface with various nozzles, no significant difference was found ($p > 0.05$). In nozzles 2 and 5, the maximum band width on the ridge was 40.56 cm and 39.43 cm, respectively. These two nozzles also exhibited the highest flow rates (847 and 834 mL min^{-1}) among the movable nozzles, due to the reduced pressure drop along the band sprayer boom (Table 2).

Table 5 The width of the band created on the ridge in comparison of different nozzles at a height of 30 cm of movable nozzle

The width of the band created on the ridge surface (cm) at a height of 30 cm of nozzle and 3 bar pressure	Nozzle number from the right side of the tractor wheel
36.50 [a]	1
40.56 [a]	2
38.78 [a]	3
37.33 [a]	4
39.43 [a]	5
36.41 [a]	6
4.03%	(CV)

Note: The means shown in each column with common letters do not have a significant difference at 0.05 level (P = 5%) (DMRT)

According to Figure 4 and Table 5, in addition to the nozzle height, which affects the band width created, the pressure in the pipe also plays a role in this relationship. Specifically, at a fixed height, the lower the herbicide solution pressure at the nozzles, the narrower the band width on the ridge surface, a point also highlighted in a previous study (Višacki et al., 2017). The results of Ooms et al. (2003) indicated that the variation in the band width formed on the soil surface by the nozzles under the same conditions, in three replications, was 8.81 cm, 6.90 cm, and 10.90 cm, respectively.

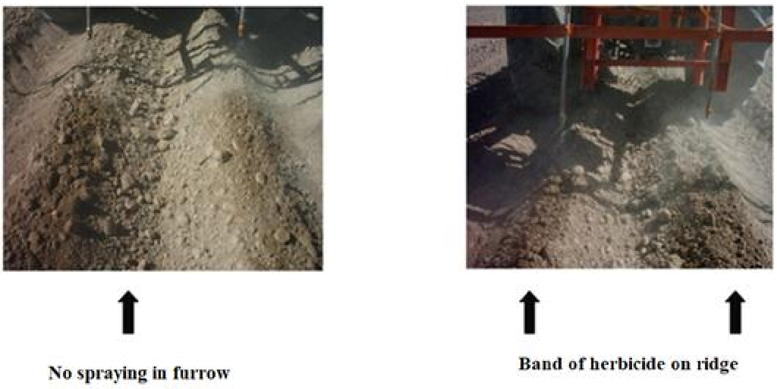

Figure 4 Creating herbicide band on the ridge using a band sprayer with a movable nozzle

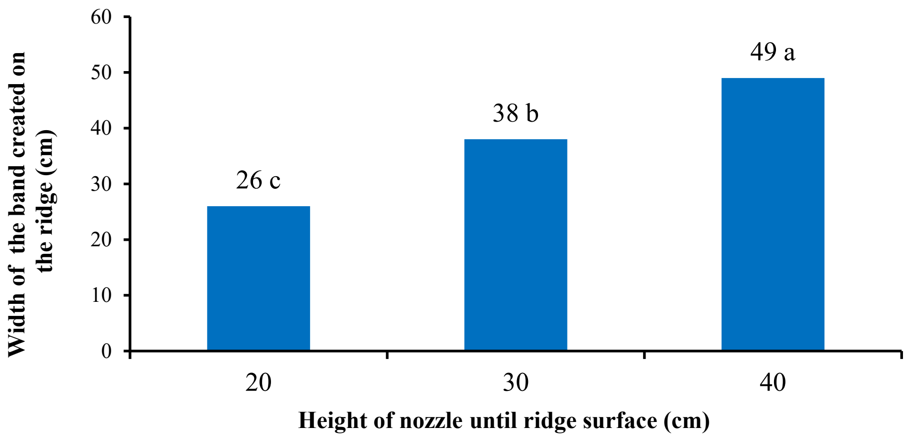

Figure 5 The mean width of the band created on the ridge at different heights of fixed nozzle

3.4 Band width created on the ridge surface by each nozzle at different heights of fixed nozzles

The comparison of the mean band widths created at nozzle heights of 20, 30, and 40 cm on the ridge surface in the band sprayer with fixed nozzles showed that the widths of the bands were 49, 38, and 26 cm, respectively. These differences were statistically significant ($p < 0.05$) (Figure 5).

The means shown in each column with common letters do not have a significant difference at 0.05 level (p = 5%) (DMRT).

The reason for this can be attributed to the higher pressure in the middle parts of the boom and the use of a separate pipe for the first to third nozzles and another separate pipe for the fourth to sixth nozzles.

As shown in Table 6, no significant differences were observed in the band widths created by nozzles placed symmetrically ($p > 0.05$). The band widths created by nozzle number 1 (at the beginning of the sprayer boom) increase towards nozzles 3 and 4 (in the middle of the sprayer boom). This can be attributed to the higher pressure in the middle sections of the boom, as well as the use of a separate pipe for nozzles 1 to 3 and another separate pipe for nozzles 4 to 6.

Table 6 The width of the band created on the ridge in comparison of different nozzles at a height of 30 cm of fixed nozzle

The width of the band created on the ridge surface (cm) at a height of 30 cm of nozzle and 3 bar pressure	Nozzle number from the right side of the tractor wheel
34.41 ^{c}	1
40.11 ^{b}	2
42.22 ^{a}	3
42.56 ^{a}	4
38.25 ^{b}	5
35.50 ^{c}	6
8.01%	(CV)

Note: The means shown in each column with common letters do not have a significant difference at 0.05 level (p = 5%) (DMRT)

Another point is that the structure of the band sprayer boom affects the width of the band formed on the ridge surface. In the band sprayer with movable nozzles, each nozzle is individually mounted on the lightweight sprayer boom using a screw. while, in the sprayer with fixed nozzles, the nozzles are installed on a heavy boom, and the vertical and horizontal movements of the boom during spraying affect the band width. This can be observed in the coefficient of variation for the movable and fixed nozzle booms, which are 4.03% and 8.01%, respectively (Tables 5 and 6).

Results from other studies have shown that pressure variation along the sprayer boom and boom shakes (both horizontal and vertical) are two critical factors in the distribution of spray droplets on the target surface and the accurate application of the herbicide solution (Ooms et al., 2003). Figure 6 shows the band formed on the ridge surface in the band sprayer with fixed nozzles.

Figure 6 Creating herbicide band on the ridge using a band sprayer with a fixed nozzle

3.5 Comparison of weed control in band spraying

The experiment was conducted in a maize field with low weed diversity, where the majority of weeds consisted of a broadleaf species known as velvetleaf (*Abutilon theophrasti*). The highest level of weed control (91.25%), was achieved with the treatment using a band sprayer equipped with a movable nozzle (S_1) at a height of 40 cm (H_3). This treatment did not show a significant difference compared to the treatment using a band sprayer with a movable nozzle (S_1) at a height of 30 cm (H_2), which achieved a mean control of 89.5% weeds ($p > 0.05$). Conversely, the lowest level of weed control (85.25%), was observed in the treatment using a band sprayer with a fixed nozzle (S_2) at a height of 20 cm (H_1), as depicted in Figure 7.

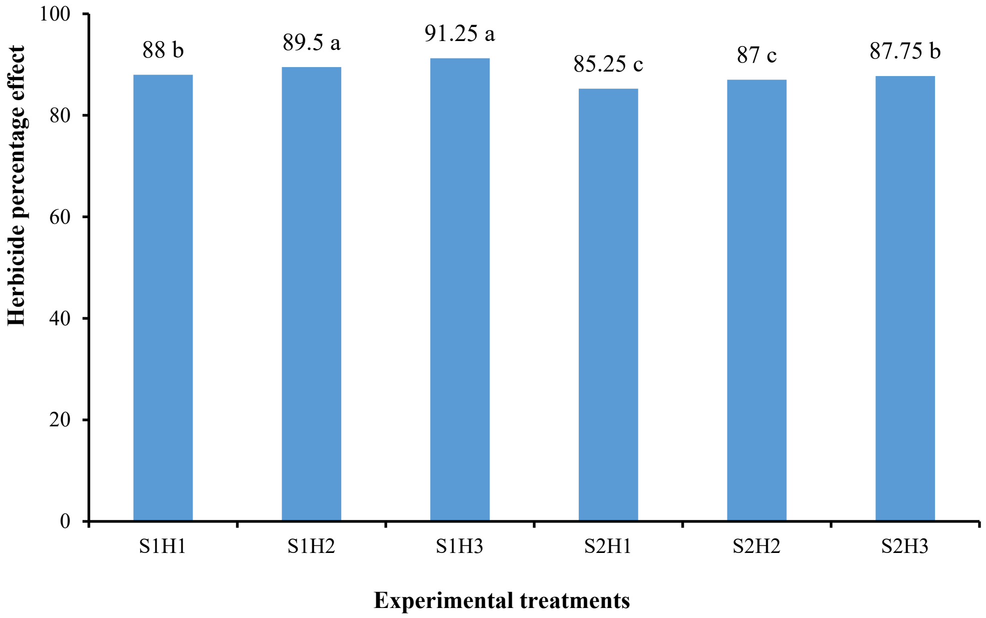

Figure 7 The herbicide percentage effect in band spraying with movable and fixed nozzle

The means shown in each column with common letters do not have a significant difference at 0.05 level (p = 5%) (DMRT).

The improved weed control at higher nozzle heights is attributed to the increased spray band width on the ridge. As the nozzle height above the ridge surface increases, the spray band widens, enabling control over a greater number of weeds. Another important factor is the type of band sprayer boom. In band spraying systems with movable nozzles, the flow rate variation between the nozzles is less pronounced compared to sprayers equipped with fixed nozzles (S_2). This results is more effective weed control and fewer weeds on the ridge. The coefficient of variation for these two types of band sprayers further confirms this observation (Table 4).

Nozzle height plays a critical role in effective weed control. At a nozzle height of 40 cm, the broader spray band ensures that the edges of the ridge are treated twice, first by band spraying and then through mechanical operations within the irrigation furrows using a sweep cultivator. In contrast, at a nozzle height of 30 cm, the narrower spray band does not reach the edges of the ridge, leaving the weeds at the ridge edges to be controlled solely by the cultivator. Precision in band spraying (particularly aligning the spray band width with the ridge width), combined with the use of a cultivator, has been reported by other researchers in effective weed management (Gursoy and Ozaslan, 2021).

3.6 Evaluation of maize grain yield in band spraying with movable and fixed nozzl

Maize grain yield was calculated on the bases of 14% (w.d.). The results of maize grain yield using band sprayers with movable nozzles (S_1) and fixed nozzles (S_2) at boom heights of 20 cm (H_1), 30 cm (H_2), and 40 cm (H_3) indicated that the highest grain yield, at 15.17 t ha^{-1}, was achieved with the use of a band sprayer equipped with movable nozzles at a height of 30 cm (H_2) (Figure 8).

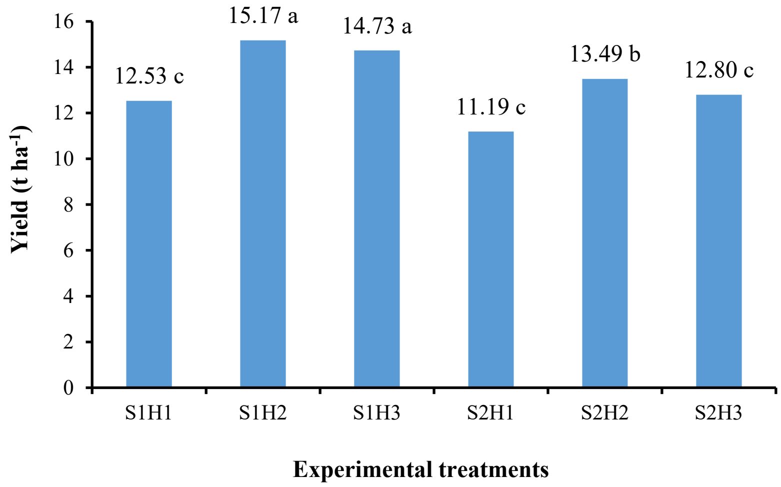

Figure 8 The mean of grain yield in band spraying with movable and fixed nozzle

The means shown in each column with common letters do not have a significant difference at 0.05 level (p = 5%) (DMRT).

Two treatments using a band sprayer with a movable and fixed nozzle, at a height of 20 cm, had the lowest yield of maize grain yield of 12.53 and 11.19 t ha^{-1}, respectively, with no significant difference ($p > 0.05$). At a nozzle height of 20 cm, the herbicide spray covers a smaller surface area of the ridge. Additionally, the sweep cultivator used for weed control in irrigation furrows is unable to effectively reach untreated areas of the ridge at this height. Furthermore, the low nozzle height of 20 cm increases the risk of the boom striking the ground. At a nozzle height of 40 cm, compared to 30 cm, both types of band sprayers exhibited reduced grain yield (Figure 8).

At a nozzle height of 40 cm, the herbicide band on the ridge had the greatest width. At this height, the edges of the ridge were exposed both to herbicide application and to mechanical operations from the cultivator. At the beginning of the growing season, the reduction in weed control is more pronounced at the 40 cm nozzle height due to the factors mentioned (Figure 7). However, throughout the growing season, weed growth increases because a fixed amount of herbicide is applied over the larger spray band at 40 cm, which contributes to a decrease in yield at this height. When the treatment with the 40 cm nozzle height was applied early in the growing season, the fixed amount of herbicide applied over the wider area did not completely eliminate the seeds of some weeds. When the weed count was performed at this height, some seeds remained viable but dormant, and therefore were not included in the count. These seeds later germinated during the growing season, leading to a reduction in yield at the 40 cm height.

Considering the aforementioned points, a nozzle height of 30 cm above the ridge level does not present the two issues previously discussed, and its effectiveness is clearly reflected in the maize grain yield measurements. Other studies have also shown that using band spraying in combination with a hoe reduced herbicide consumption by 60% without negatively impacting maize yield (Vasileiadis et al., 2015). Furthermore, to minimize the frequency of band spraying and prevent yield reduction, proper nozzle height and spray band width have been emphasized (Gerhards et al., 2020). Additionally, a 76% reduction in pesticide use in band spraying without yield loss has also been reported for other row crops such as sugar beet (Carballido et al., 2013).

3.7 Comparison of weed control and crop yield in band spraying vs. broadcast spraying methods

Maize grain yield was calculated on the bases of 14% (w.d.). The results of the t-test comparing the means of band spraying with movable nozzles at a height of 30 cm (the optimal band spraying operation method) and broadcast spraying showed no significant difference in weeds control in the experimental plots between the two methods ($p > 0.05$). The maize grain yield was also similar between the band spraying and broadcast spraying methods, with yields of 15.17 and 14.98 t ha^{-1}, respectively, showing no significant difference (Table 7).

Table 7 Evaluation of mean differences between band and broadcast spraying using t-test

t-test	Broadcast spraying	Band sprayer at the nozzle height of 30 cm	Trait
-1.654^{ns}	88.25	89.5	Herbicide percentage effect
1.352^{ns}	14.98	15.17	Yield (t ha^{-1})

Note: ^{ns}: No significant difference

In the broadcast spraying method, herbicide application was carried out on both the furrows and ridges, while mechanical weed control in the furrows was performed using a sweep cultivator. The acetachlor herbicide was applied before the maize emerged. When the maize plants reached a height of 20-25 cm, weeds in the furrows, having grown due to irrigation, were controlled using the sweep cultivator. In the band spraying method, only the ridges were sprayed, while mechanical operations were conducted in the furrows .

Considering the environmental impacts of herbicide use and the lack of significant difference between the broadcast and band spraying methods, band spraying is a suitable alternative to broadcast spraying. Additionally, in maize, due to the plant structure, shading over the weeds is significant after chemical and mechanical control operations, ensuring effective weed management throughout the growing season. The combination of band spraying and mechanical weed control in maize plants has also been reported by several other researchers (Ozaslan et al., 2024; Vasileiadis et al., 2015).

3.8 Reduction of herbicide consumption at different nozzle heights and spray band widths

The amount of acetochlor herbicide applied in the experimental maize field was set at 4 L ha^{-1}. In band spraying with both movable and fixed nozzles, the reduction in herbicide consumption was achieved through calibration .

In the band sprayer with movable nozzles, at a nozzle height of 20, 30 and 40 cm, the herbicide consumption was reduced by 62.7%, 46.7% and 38.7%, respectively (Figure 9).

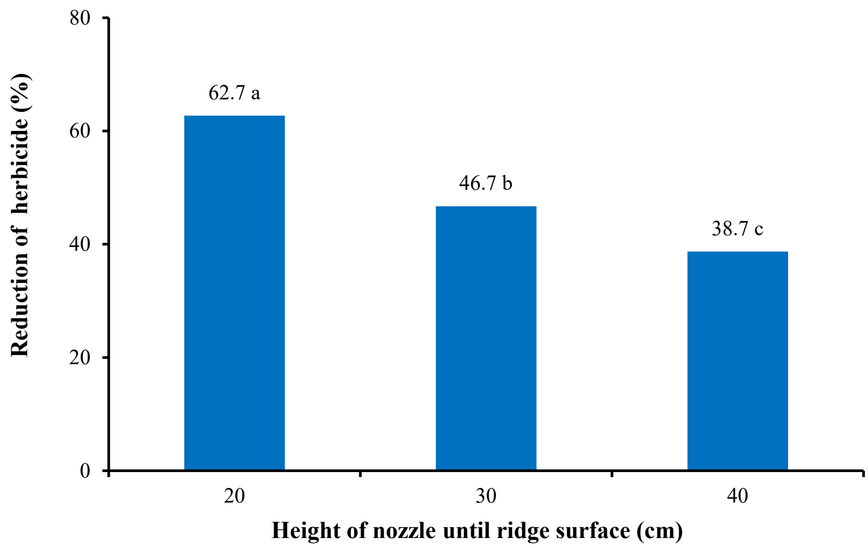

Figure 9 The mean reduction of herbicide at the different height of nozzles in band spraying

The means shown in each column with common letters do not have a significant difference at 0.05 level (p = 5%) (DMRT).

At nozzle heights of 20, 30, and 40 cm, the nozzle flow rates were consistent, and the concentration of the herbicide solution did not change. In band spraying, the width of the herbicide band on the ridge showed a direct relationship with the nozzle height. The highest percentage of herbicide consumption reduction occurred at a nozzle height of 20 cm, followed by reductions at 30 cm and 40 cm, respectively. According to the results obtained, the reduction in herbicide consumption of acetochlor in band spraying is considerable compared to broadcast spraying (100% herbicide spraying).

4 Conclusion

As the nozzle height increased from 20 to 30 and 40 cm, the mean spray band width in band spraying was 27, 39, and 47.5 cm, respectively. The spray band width on the surface soil was wider than the set nozzle height (20, 30, and 40 cm), which could be attributed to boom movement during spraying operations and the condition of the surface soil. At a nozzle height of 20 cm, a smaller band was created on the ridge, and as a result, parts of the ridge were neither exposed to the herbicide nor to mechanical operations by the sweep cultivator. In contrast, at a nozzle height of 40 cm, with wider spray bands greater than 40 cm on the ridge, both the edges of the ridge were exposed to the cultivator and the herbicide. A nozzle height of 30 cm was the optimal height that created a spray band matching the ridge width, while also exposing the furrows and ridge edges to mechanical operations with the sweep cultivator. In general, at all nozzle heights of 20, 30, and 40 cm, the edges of the nozzle spray were more diluted compared to the center. At a nozzle height of 20 cm, due to the narrow spray width, the diluted edges of the nozzle spray on the surface soil were not exposed to the cultivator. However, at a nozzle height of 30 cm, the proportional relationship between nozzle height and the spray width on the ridge allowed the cultivator blades to cover the diluted edges of the nozzle spray. At a nozzle height of 40 cm, the spray width was wider than the ridge width, causing some areas of the furrows and ridge to be exposed to both chemical and mechanical control operations. The reduction in herbicide consumption in the band sprayer with movable nozzles at heights of 20, 30, and 40 cm were 62.7%, 46.7%, and 38.7%, respectively. While the significant reduction in herbicide consumption at a nozzle height of 20 cm was noteworthy, it is not recommended due to the potential risk of boom contact with the ridge. The results of maize grain yield performance at a nozzle height of 30 cm using a band sprayer with movable nozzles indicated that this height did not show a significant difference compared to the broadcast spraying method, with a 46.7% reduction in herbicide consumption. Therefore, based on the obtained results, the band spraying method with movable nozzles at a height of 30 cm, considering the advantage of adjustable nozzle distances both horizontally and vertically, can be an appropriate alternative to broadcast spraying for weed control and achieving optimal crop performance in maize.

References

Alagbo, O., M. Spaeth, M. Saile, M. Schumacher, and R. Gerhards. 2022. Weed management in ridge tillage systems- A Review. *Agronomy*, 12(4): 910.

Alba, O. S., L. D. Syrovy, H. S. N. Duddu, and S. J. Shirtliffe. 2020. Increased seeding rate and multiple methods of mechanical weed control reduce weed biomass in a poorly competitive organic crop. *Field Crop Research*, 245: 107648.

Alptekin, H., A. Ozkan, R. Gurbuz, and M. Kulak. 2023. Management of weeds in maize by sequential or individual applications of pre- and post-emergence herbicides. *Agriculture*, 13(2): 421.

Andert, S., and A. Ziesemer. 2022. Analysing farmers' herbicide use pattern to estimate the magnitude and field-economic value of crop diversification. *Agriculture*, 12(5): 677.

Balsari, P., E. Gil, P. Marucco, J. C. van de Zande, D. Nuyttens, A. Aerbst, and M. Gallart. 2017. Field crop sprayer potential drift measured using test bench: Effects of boom height and nozzle type. *Biosystems Engineering*, 154: 3-13.

Carballido, J., A. Rodríguez-Lizana, J. Agüera, and M. Pérez-Ruiz. 2013. Field sprayer for inter- and intra-row weed control: Performance and labor savings. *Spanish Journal of Agricultural Research*, 11(3): 642-651.

Chandel, N. S., A. K. Chandel, A. K. Raul, K. R. Solanke, and C. R. Mehta. 2021. An integrated inter- and intra-row weeding systems for row crops. *Crop Protection*, 145: 105642.

Dragomir, V., B. Ioan Sebastian, B. Alina, P. Victor, L. Tanasă, and D. Horhocea. 2022. An overview of global maize market compared to Romanian production.

Romanian Agriculture Research, 39: 535-544.

FAO. 2023. Food and Agricultureal Organization of the United Nations. Rome, Italy: FAO.

Gerhards, R., J. F. Weber, and C. Kunz. 2020. Evaluation of weed control efcacy and yield response of inter-row and intra-row hoeing technologies in maize, sugar beet and soybean. *Landtechnik*, 75(4): 247-260.

Gerhards, R., K. Hüsgen, and K. Gehring. 2024. Evaluation of mechanical and combined chemical with mechanical weeding in maize (*Zea mays* L.), soybean (*Glycine max* (L.) Merr. and winter wheat (*Triticum aestivum* L.). *Plant, Soil and Environment*, 70(12): 751–759.

Gursoy, S., and C. Ozaslan. 2021. Evaluating the Performance of Rotary and Tine Inter -Row Cultivators at Different Working Speeds. *Journal of Agricultural Science and Technology*, 23(6): 1255-1267.

Hassen, N. S., and N. A. C. Sidik. 2019. Laboratory investigation of nozzle type, size and pressure effects on spray distribution. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 61(1): 140-146.

Jensen, P. K., and I. Lund. 2006. Static and dynamic distribution of spray from single nozzle and the influence on biological efficiency of band application of herbicides. *Crop Protection*, 25(11): 1201-1209.

Kunz, C., J. F. Weber, G. G. Peteinatos, M. Sökefeld, and R. Gerhards. 2018. Camera steered mechanical weed control in sugar beet, maize and soybean. *Precision Agriculture*, 19(4): 708-720.

Lamare, A., I. Zwertvaegher, D. Nuyttens, P. Balsari, P. Marucco, M. Grella, A. Caffini, N. Mylonas, S. Fountas, and J. Douzals. 2022. Performance of a prototype boom sprayer for bed-grown carrots based on canopy deposition optimization, ground losses and spray drift potential mitigation in semi-field conditions. *Applied Sciences*, 12(9): 4462.

Lamichhane, J. R., L. Alletto, W. Cong, E. Dayoub, P. Maury, D. Plaza-Bonilla, M. Reckling, S. Saia, E. Soltani, G. Tison, and P. Debaeke. 2023. Relay cropping for sustainable intensification of agriculture across temperate regions: Crop management challenges and future research priorities. *Field Crops Research*, 291: 108795.

Loddo, D., L. Scarabel, M. Sattin, A. Pederzoli, C. Morsiani, R. Canestrale, and M. G. Tommasini. 2020. Combination of herbicide band application and inter-row cultivation provides sustainable weed control in maize. *Agronomy*, 10(1): 20.

Nation, H. J. 1982. The dynamic behaviour of field sprayer booms. *Journal of Agricultural Engineering Research*, 27(1): 61-70.

Ooms, D., R. Ruter, F. Lebeau, and M. F. Destain. 2003. Impact of the horizontal movements of a sprayer boom on the longitudinals spray distribution in the field conditions. *Crop Protection*, 22(6): 813-820.

Osuch, A., P. Przygodziński, P. Ryback, E. Osuch, I. Kowalik, L. Piechnik, A. Przygodziński, and M. Herkoviah. 2020. Analysis of the effectiveness of shielded band spraying in weed control in field crops. *Agronomy*, 10(4): 457.

Ozaslan, C., S. Gürsoy, and A. DiTommaso. 2024. Band herbicide application combined with inter-row cultivation as a sustainable weed management strategy for reducing herbicide use: A meta analysis. *Crop Protection*, 175: 106474.

Partal, E., and M. Paraschivu. 2020. Results regarding the effect of crop rotation and fertilization on the yield and qualities at wheat and maize in South of Romania. *Agronomy*, 63(2): 184-189.

Raja, R., T. T. Nguyen, D. C. Slaughter, and S. A. Fennimore. 2020. Real-time weed-crop classification and localosation technique for robotic weed control in lettuce. *Biosystems Engineering*, 192: 257-274.

Smith, D. W., B. G. Sims, and D. H. O'Neill. 1994. Testing and Evaluation of Agricultural Machineny and Equipment. Rome, Italy: FAO.

Vasileiadis, V. P., S. Ottoa, W. Van Dijk, G. Urekc, R. Leskovšek, A. Verschwele, L. Furlane, and M. Sattina. 2015. On-farm evaluation of integrated weed management tools for maize production in three different agro-environments in Europe: Agronomic efficacy, herbicide use reduction, and economic sustainability. *European Journal of Agronomy*, 63: 71–78.

Višacki, V., A. Sedlar, R. Bugarin, J. Turan, and P. Burg. 2017. Effect of pressure on the uniformity of nozzles transverse distribution and mathematical model development. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 65(2): 563-568.