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Performance Evaluation of a Water Seed Drill

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Abstract: Water content plays a crucial role in seed development, particularly at the seed sowing stage, and it ensures good seed germination. A water seed drill was designed and developed to provide an optimum quantity of water that is required for the soil in the same furrow, right after seed placement. This soil moistening method not only improves the moisture level in the field, but it also saves a large amount of water by applying the needed water quantity in the line of sowing after seed placement. The water seed drill consisted of a wheat seed drill, a water application system, and a tank with 400 L capacity. The water seed drill yielded a 48% higher germination count than when wheat is planted through a conventional method. The data recorded also showed that the water seed drill raised the soil moisture to 24% from the existing 13% soil moisture content. The total operational cost of the water seed drill was 2.57-fold greater than the conventional seed drill, but the output cost of the water seed drill was 2.15 times (49,000 Rs/ha) more than that of the conventional seed drill.

Keywords: mechanize farming; water seed drill; line sowing; germination count and rainfed machine

1. Introduction

The increasing worldwide population is a serious problem, as the agriculture sector needs to produce large amounts of food to meet their requirements. Efforts are underway to enhance crop production through an increase in per hectare yield. The low yields per hectare of wheat crops are due to late sowing, inaccurate planting methods, and shortages of irrigation water. Developing countries are facing a big challenge to meet the irrigation needs for crop production. Rainfed agriculture in Pakistan is mainly dependent on rainfall irrigation. The major impediment to enhancing wheat yield in the arid (Barani) area of Pakistan is a delay in sowing, due to little or no moisture being present in the soil [1].

Line sowing is desirable, because it allows for more even seed spacing, an accurate depth of planting, and proper space for weeding. In comparison with the broadcasting of seeds, the drill sowing method gives higher yields, due to the greater uniformity of seed distribution and accurate seeding depth. A higher germination rate and more uniform crop-stand have been found in the seed drill method [2]. The sowing of wheat at a proper time makes a significant contribution to achieving higher yields [3]. In late sowing, low temperature affects seed germination, which delays tillering, resulting in less time being available for the proper growth of plants [4]. Experiments have shown that the sowing of wheat after November 15 decreased the yield by 37 kg/ha/day, despite better management and the use of proper inputs [5]. Sowing of wheat crops at the proper time led to better seed germination, proper growth of plants, less incidence of diseases, and higher yields per hectare [6].

Irrigation plays a crucial role, particularly at the seed sowing stage [7,8]. Therefore, a need has emerged to optimize water usage by refining the tillage, as well as the irrigation method, for better seed sowing and germination. The application of the water seed drill fulfills the demands of soil moisture at the seed sowing stage, because agronomic practices, such as sowing techniques, not only seek optimum plant growth, but also enable the seeds to utilize input resources more effectively toward better germination and growth [9]. Mechanized irrigation is the application of the desired quantity of water to the field for effective utilization, which can save time and reduce water losses.

The moisture availability and temperature of soils are the key factors that regulate seed germination in an arid climate [10,11]. Seed germination is the most critical growing stage in arid soil, but the available soil moisture for seed germination is a main cause of poor germination and un-germinated seeds [12,13]. Soil moisture availability is directly dependent on soil types, and it is the key reason for seed germination [14]. Moisture is needed for seed germination and tiller growth, and it may therefore play a critical role in evaluating the seed distribution pattern [15–17].

Several studies may have enhanced seed germination in conditions of low soil moisture availability by maintaining its capabilities at lower water content in the soil [18], and encouraging rapid seed germination in order to utilize temporally and partially restricted soil-available water [16,19–22] and a high root:shoot ratio [23,24]. The impact of sowing techniques and water application systems on soil moisture and the germination index of sorghum crops has been investigated by many researchers, to reduce the irrigation water at specific stages, minimizing the loss of seed germination from water stress. Knowledge is needed about the stage of crop germination at which a small quantity of irrigation will yield a greater water use efficiency and germination index. The link between seed germination and water quantity for irrigation has been a major focus of research in arid and semi-arid agriculture [25–27]. There is a need to develop technology that could save irrigation water and provide an easy approach for farmers [28].

Rain water conservation practices for sowing are the most attractive sources of soil moisture to growers, due to the reduced cost of production in comparison with conventional sowing practices and the storage of moisture for seed sowing. However, this method is not always appropriate, because rainfall is a non-reliable source of soil moisture, particularly at the seed sowing stage [29].

The optimum solution for overcoming the problem of soil-available water shortages at the seed sowing stage discussed above is a water seed drill, which helps to sow the crop at an appropriate time by adding soil water and thus providing a better environment to seed germination. Water can easily be optimized by using a water seed drill for the sowing of crops. This also has a great importance for seed germination and crop production in the rainfed regions of Pakistan. A water seed drill not only helps in improving the germination of the crop, but it also saves the water that is required for irrigation. To achieve this objective, and to adopt resource conservation technology, the Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi, Pakistan, has designed, developed, and tested a water seed drill. This experiment was conducted to check the effect of this technology on soil moisture, seed germination, the number of tillers per plant, and the wheat yield. The objective was to replace conventional sowing with water seed drill sowing in arid and semiarid regions, in order to ensure the timely sowing of the crop in the absence of rainfall.

2. Material and Methods

A water seed drill was designed and developed by the Faculty of Agricultural Engineering & Technology, PMAS Arid Agriculture University, Rawalpindi, in 2015. The water seed drill was created with locally available materials and manufacturing techniques.

2.1. Water Seed Drill

The water seed drill was developed to fulfill the soil moisture deficit in the soil, particularly at the seed sowing stage. The water seed drill is a combination of a common seed drill and a water application system. A water application system was mounted onto the seed drill, to apply water into the field during the sowing of the seed. This water application system consisted of mounting frame, a water tank, a water delivery pipe, injectors, and water tubes, as shown in Figure 1. The water delivery tube drops a specified quantity of water at the same depth as where seed is dropped. The seed drill can be easily mounted and de-mounted on a common tractor. The water seed drill is 2134 mm wide with nine furrows each, and it is separated by 229 mm of space. The water seed drill can also be used independently without the water application system if required, when the soil already has the desired moisture content. The water seed drill applies water at the same depth as that of the seeds. The salient features of the water seed drill are presented in Table 1.

Figure 1. The application of the water seed drill in the field for wheat sowing.

Table 1. Salient features of the water seed drill.

Parameter	Values
Empty weight (seed drill + water application system)	750 kg
Volume of seed box	50 kg
Volume of fertilizer box	50 kg
Volume of water tank	400 L
Power requirement (tractor horsepower)	65 hp
Working width	2.13 m
Number of rows of furrow openers	9
Row spacing	23 cm
Effective field capacity	0.54 ha/h
Operational cost	Rs. 32,242/h

2.2. Water Application System

The water application system was designed and developed to apply the required amount of water into the soil along with seed, for better seed emergence. This system consists of a water tank, a main valve, a water distribution pipe 381 mm in diameter, water injectors, and water delivery tubes 12.7 mm in diameter, as shown in Figure 1. The tank was created in three sections using a 24-gauge milled steel sheet. The size of the middle section was 914 mm × 610 mm, and the two outer sections were 457 mm × 305 mm, with a tank depth of 483 mm, and a tank capacity of 400 L water. The required quantity of water was delivered to the soil through water delivery tubes. The quantity of water flowing into the soil could be controlled by the main valve and valves near each water injector.

2.3. Seed Drill

A common Rabi seed drill was used to incorporate the necessary features of the water application system. The water application system, injectors, and water delivery tubes were properly fitted to the seed drill with a tractor-mounting mechanism.

The water seed drill was tested in the field for a performance evaluation with respect to water application, germination count, and the number of tillers and wheat yield. The drill was also tested in the dry field of Koont farm in Rawalpindi, Pakistan, along with the conventional method of sowing under the same field conditions. The water seed drill was calibrated both for water and seed prior to operation under field conditions. Water flow was measured at different openings of the main valve. To calibrate the drill, its seed box was filled with seed, and the drill was hitched up with the tractor at least 30 cm above the ground. Plastic bags were placed under each seed delivery tube. The drive wheel was spun by hand at a normal field speed up to the required number of revolutions. Then, a measured weight of the collected seed was compared with the calculated seed weight, using the following equation [4].

$$W = [(d * n * \pi * D * N) * G]/10{,}000$$

where,

W = weight of seed (kg)
d = row-to-row distance (m)
n = number of rows
D = effective diameter of the drive wheel (m)
N = number of drive wheel revolutions
G = seed rate (kg/ha)

The area of 6.58 hectares (16.25 acres) was divided in 13 plots of 0.5 ha (45 m × 40 m) each. 12 were sown with a water seed drill, and the 13th plot by conventional methods, as shown in Figure 2. The sowing operation was performed with a forward speed of 4.25 km/h and a maximum water flow rate of 90 mL/s (90, 70, and 50 mL/s), based on the existing moisture content in the soil, while the conventional plot was sown at same speed, with no water application. The data for moisture content (%), germination count (GC/m^2), number of tillers (tiller/m^2), and wheat yield (kg/ha) were collected. A wheat yield comparison for the last 17 wheat seasons from 2000-2001 to 2016-2017 was also performed.

The moisture content in the field was measured at two different depths, i.e., 3 and 6 inches, both before crop sowing and after the sowing of the crop with the water seed drill. By using a soil moisture sensor (HH2, ΔT devices), the seed germination rate was calculated in order to know how many plants emerged in a unit area (1 m^2) by counting the number of plants that emerged every day after emergence started. In every plot, three points of 1 m^2 were randomly selected to observe plant emergence. The plant tillering was also measured from the same selected unit area as described [30]. The average value of these three unit areas was then used. The data of rainfall for the last 17 wheat seasons, including the current studied crop periods (2017–2018), was collected from the Pakistan meteorological department (Govt. of Pakistan), Chakwal regional station [31]. The local standard rental cost of land preparation implements and market price of crop input were used to estimate the operational cost for water seed drills and conventional methods. The economic comparison was also performed by using the costs of agricultural machinery and crop inputs.

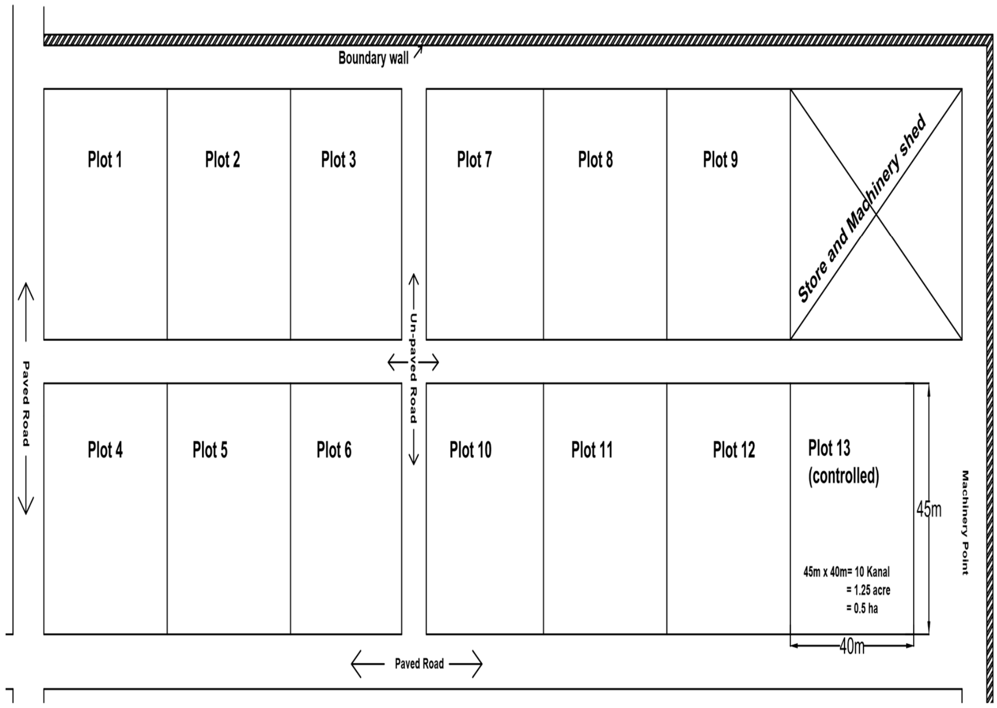

Figure 2. The experimental field layout.

3. Results and Discussion

3.1. Water Seed Drill Calibration

The water seed drill was tested in the field under variable flow rates and tractor speeds. The water applied was determined at different flow rates and tractor speeds. The seed quantity was also estimated before wheat sowing, as shown in Table 2. The flow rates observed at three different injector openings (full open, two-thirds open, and one-third open) were 90, 70, and 50 mL/s respectively, but sowing was performed with the maximum flow rate. The designed seed rate of the seed drill varied between (0–250 kg/h), but for wheat sowing, the seed rate used was 125 kg/ha (6 kg/kanal). The seed drill calibration was performed, and the seed rate was calculated as 50 kg/acre (125 kg/ha).

Table 2. Calibration of the wheat seed drill.

Parameter	Unit	Description
Width of seed drill	meter	2.13 m
Circumference driving side wheel	meter	2.13 m
Field area	hectare, (m^2)	1, (3557)
No of revolutions per hectare	rev./ha	2200
Reduced revolutions (Reduction factor, 20)	2200/20	110
Seed collected from nine furrows at 110 rev.	kg	6.27
Total seed required for one hectare	(6.27 × 20) kg	125.4

3.2. Soil Moisture Content

The moisture content in the field was measured at two different depths, i.e., 3 and 6 inches, both before crop sowing and after the sowing of the crop with the water seed drill. The average moisture content in all plots was enhanced by the operation of the water seed drill, i.e., 18.3% soil moisture content at 3 inches, which was twice that of the already existing average soil moisture content in the same plots (9.12%), as shown in Figure 3.

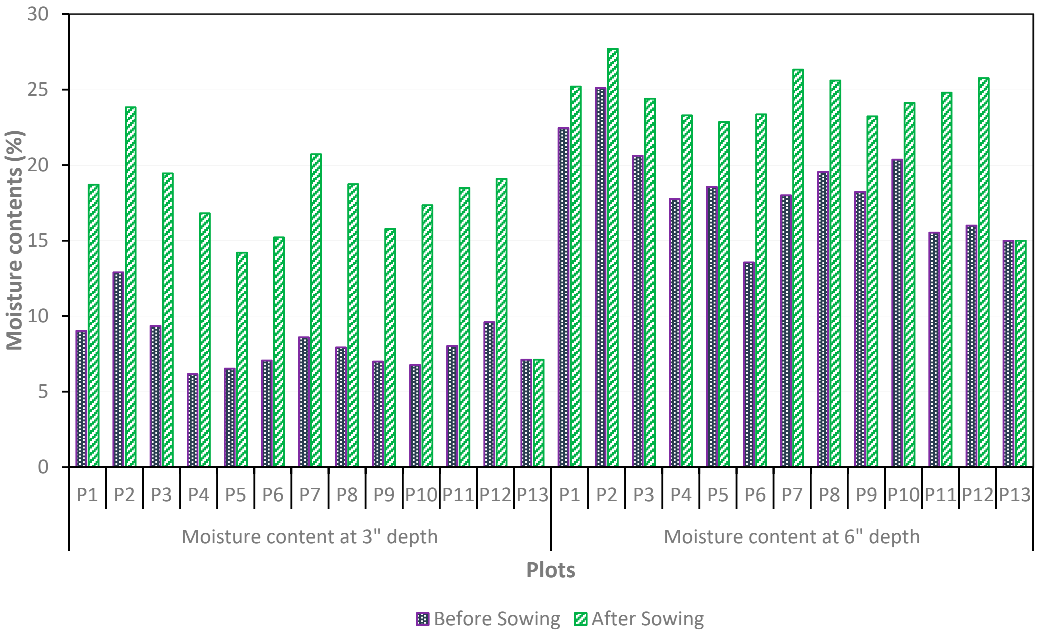

Figure 3. Soil moisture contents of different plots before and after wheat sowing at different depths.

The data showed the fluctuation in moisture content of all plots both at 3 and 6 inches depth. At 3 inches depth, the water seed drill gave maximum soil moisture content in plot 2, followed by plot 7 and plot 12 (i.e., 23.8, 20.7, and 19.1%), respectively, and a minimum of 14.2% in plot 5. The same trend in moisture content was found at 6 inches depth, while in the conventionally sown plot (P13), there was no moisture being applied through the water seed drill. In the conventional method, sowing was done at already existing moisture conditions that were, on average, 7.12% and 15% at 3 and 6 inches depth, respectively. The maximum moisture was measured in plot 2 (23.83%), which was 1.85 times more than the already available soil moisture content (12.9%). The moisture content at 6 inches depth was measured to be 27.7% in the same plot after the application of the water seed drill. The complete trend of moisture content in the field at 3 and 6 inches depth is shown in Figure 3.

3.3. Seed Germination Rate

The tillage system resulting in early seedling growth tends to have greatest yield, and the rate of plant emergence might provide better understanding of the soil conditions created by a particular tillage system than measurement of soil's physical properties [32]. Seed germination commenced on the eighth day of sowing, and the data of the germinated seeds were collected for 14 days right after seed emergence occurred. Figure 3 shows the average number of germinations per m^2 recorded. The result of the germination count in every plot showed a significant effect of the water seed drill when compared to conventional sowing. Seed germination counts (plants·m^{-2}), both per day and cumulative, are shown in Figure 4. An analysis of the data in all plots revealed that the daily germination of wheat increased up to day 7, both in the water seed drill and conventional sowing methods, and then it fell. However, the daily emergence in conventional sowing was less than that of the water seed drill method. The maximum daily seed emergence was observed to be 26 and 22 with the water seed drill and conventional sowing methods, respectively. The trend in cumulative germination is also shown in Figure 3, where there is a big difference in the germination of wheat by using the water seed drill when compared to the conventional method. The final seed germination was found to be 53 plants/m^2 more with the water seed drill when compared to conventional sowing. The total number of plants that emerged in every plot is shown in Figure 4. The maximum seed germination rate was found to be 94%

in plot 2, followed by plot 7 with 79.8%, while plot 13 (controlled sowing) yielded a seed germination rate of 48%.

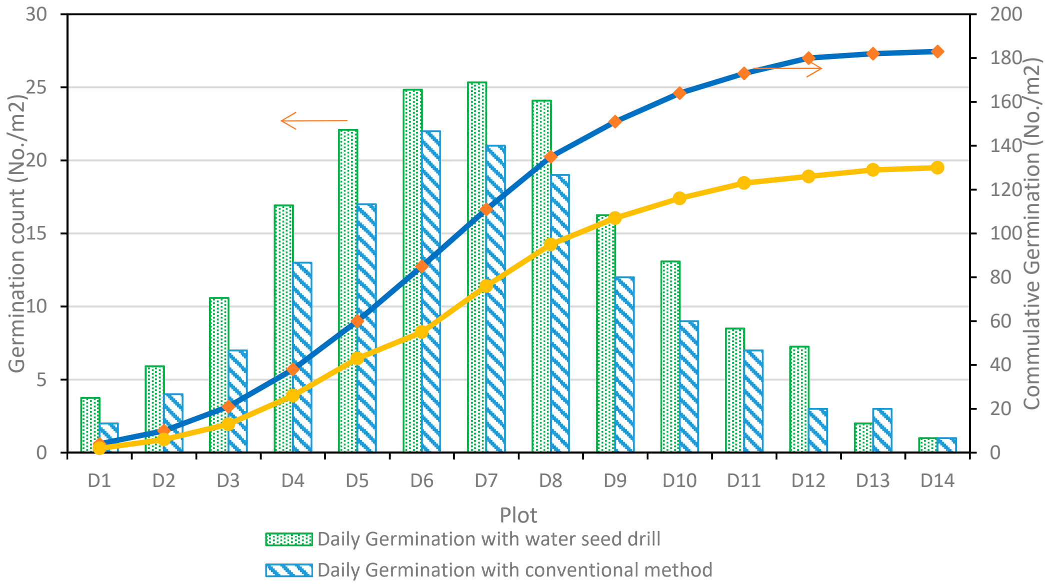

Figure 4. Daily and cumulative seed germination count of the wheat crops.

3.4. Number of Tillers

Data concerning the number of tillers in accordance with moisture content at two depths, i.e., 3 and 6 inches, are presented in Figure 5. The figure depicts a trend of the moisture content added to the existing soil moisture through the water seed drill at both depths and its ultimate impact on the tillers. The analysis of data clearly showed that a maximum number of tillers (tillers·m^{-2}) of 581 was recorded in the plots sown with the water seed drill, while the lowest number of tillers was recorded at 260 in the plots sown with the conventional seed drill. The difference in the number of tillers in the plots sown with the water seed drill and that of the conventional seed drill was 321 tillers. The plots with higher soil moisture content had a larger number of tillers. Moisture stress directly affected the development, growth, and yield of a crop, and the results were similar to those reported by [33].

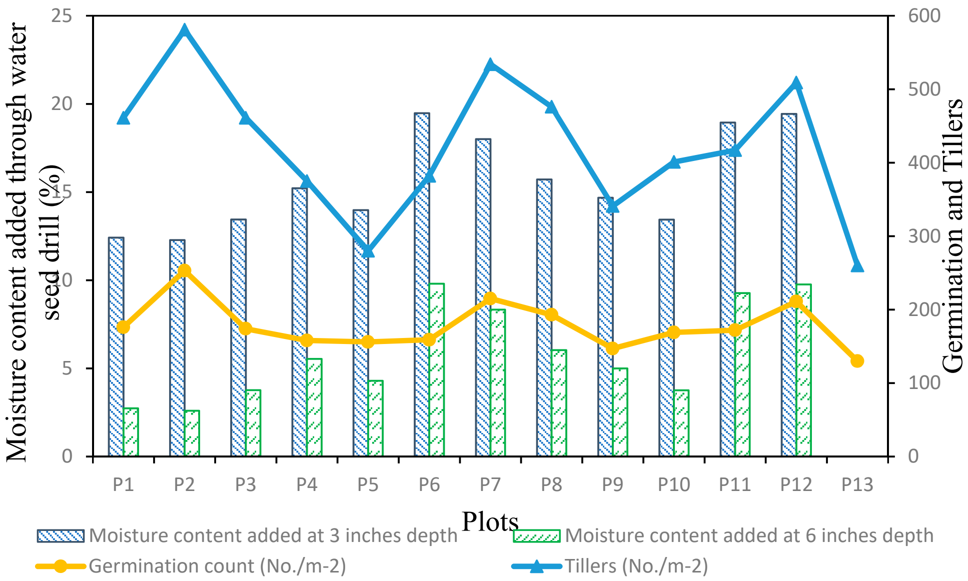

Figure 5. Seed germination count and number of tillers of wheat crops in all plots.

3.5. Effect of Moisture on Wheat Yield

Figure 6 depicts the trend of moisture content added through the water seed drill in the field at both 3 and 6 inches of depth and the impact on wheat yield. The data showed that the maximum wheat yield produced was 2613 kg/ha in plot 2, followed by 2410 and 2290 kg/ha in plot 7 and plot 12, respectively, while a minimum yield of 1214 kg/ha was observed in the plot sown with the conventional seed drill. [34,35] reported that moisture content has a direct relationship with crop growth, the number of grains per spike, and the ultimate wheat yield. [36] states that the average grain weight per spike is 2.17 g.

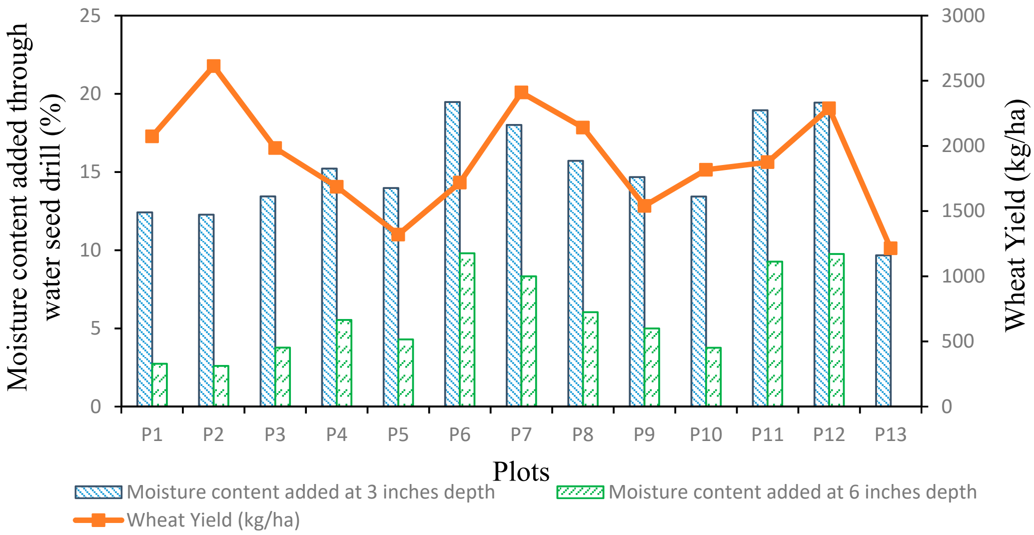

Figure 6. The effect of moisture content on germination, tillers, and wheat yield in different plots.

Figure 7 shows the difference in soil moisture content, the germination of seeds, the number of tillers measured, and the yield of wheat when sown with the water seed drill or under the conventional method. It is also clear from Figure 7 that the greater the soil moisture, the higher the germination and yield of the crop.

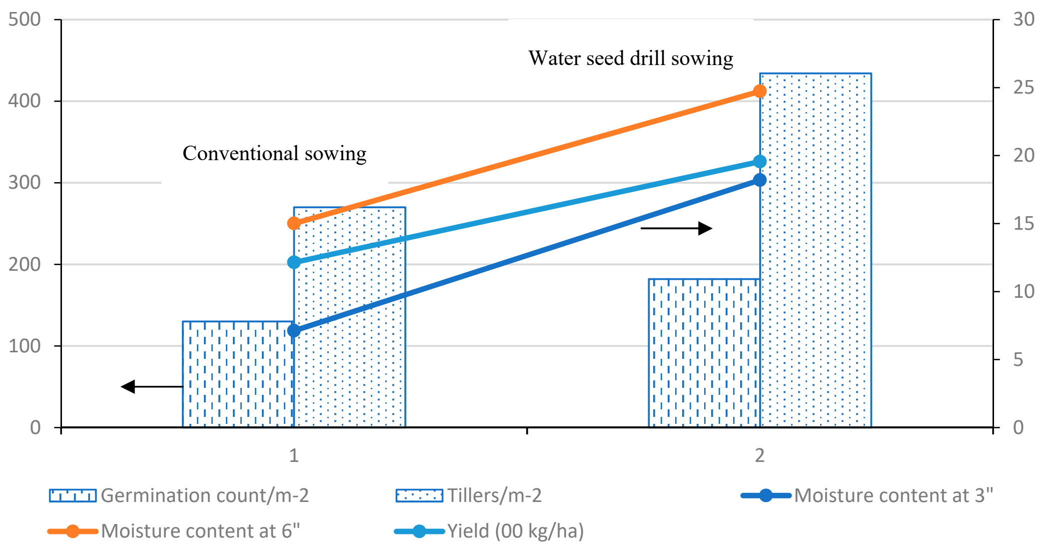

Figure 7. A comparison of moisture content on germination, tillers, and wheat yield between water seed drill and conventional sowing.

3.6. Effect of Seasonal Rainfall on Wheat Yield

The 17-seasonal rainfall and annual wheat yield of Koont farm is shown in Figure 8. Seasonal rainfall had a significant effect on the wheat yield in rainfed areas. The wheat seasons that had greater seasonal rainfall gave greater wheat yields, and the wheat seasons with less rainfall produced low wheat yields. The maximum wheat yield season was 2014–2015, with 1076 mm seasonal rainfall, with 2570 kg/ha wheat yield, while the minimum wheat yield season was 2000–2001, with 33.5 mm seasonal rainfall, and 676 kg/ha wheat yield.

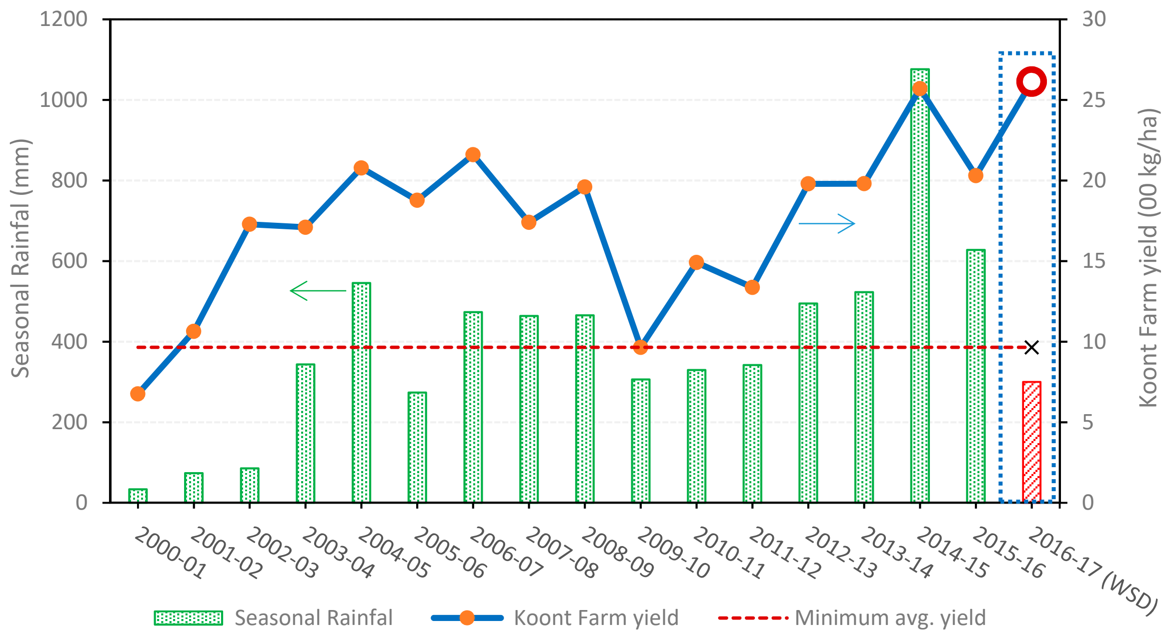

Figure 8. A comparison between the wheat yield and seasonal rainfall for 17 wheat seasons from 2000-2001 to 2016-2017.

In the wheat season of 2009–2010, Koont research farm received 306 mm seasonal rainfall and had 965 kg/ha wheat yield. The current wheat season (2016–2017) was also under rain stress at 300 mm rainfall, and wheat was sown with the water seed drill. The plots sown with the water seed drill gave 2613 kg/ha wheat yield, despite the low rainfall, and this yield was 2.7 times more than the expected wheat yield. The fluctuations in wheat yield with the seasonal rainfall are shown in Figure 8. The correlation between annual rainfall and wheat yield was found to be positive and strong, with an R-square value equal to 0.94.

3.7. Cost Analysis

The cost analysis for the water seed drill was performed to evaluate the total operational cost per hour (Table 3). The operational cost of water seed drill was Rs. 2686.18/h compared with the conventional drill (Rs. 1042/h). The higher operational cost of the water seed drill was because of its higher purchase price Rs. 125,000, and the water cost, Rs. 1561.25, at 0.25/L, as shown in Table 4.

A comparison of the costs, both for the water seed drill and the conventional seed drill, was made in order to evaluate the differences, as shown in Figure 4. The cost comparison included the cost of machinery, the land preparation cost, crop inputs cost, and labor cost. The total fixed cost per hour of the water seed drill was 2.77 times more than that of the conventional seed drill, while the total one hour operational cost of the water seed drill was 2.57 times more than that of the conventional seed drill. The additional cost in the water seed drill was 1561.25 Rs./ha for the application of water, but the yield obtained with water seed drill sowing was 2.15 times more than conventional seed drill sowing. The benefit-cost ratio for the water seed drill and the conventional seed drill are 1.49 and 0.27, respectively.

Table 3. Economics of wheat sowing with the water seed drill and the conventional seed drill.

Particulars	Rate	OPERATIONAL COST (Rs./ha)	
		Water Seed Drill	Conventional Seed Drill
Land Preparation			
MB plow, one pass	1750/ha	1750	1750
Disk plow, two passes	1500/ha	3000	3000
Cultivator, three passes	2000/ha	6000	6000
Rotavator, one pass	1750/ha	1750	1750
Planking, two passes	2000/ha	4000	4000
Sowing			
Seed (125 kg/ha @ Rs. 1800/40 kg)		5625	5625
Fertilizer, (Diammonium phosphate, 125 kg/ha @ Rs. 3000/50 kg and urea, 125 kg/acre @ Rs. 1500/50 kg)		11,250	11,250
Water, 7904 L/ha @ 0.25 Rs./L		3,122.5	0
Labor @ 1000/day		165	165
Total cost of sowing		36,663	33,540
Wheat yield (kg/ha)		2613	1214
Wheat yield cost @ 1400/40 kg		91,455	42,490
Benefit–cost ratio (BCR) = (Benefit−Expenditure)/Expenditure		1.49	0.27

Table 4. Operational cost of the water seed drill and the conventional drill for wheat.

Item	Tractor (Fiat-640)	Water Seed Drill	Conventional Drill
Purchase price	800,000	125,000	45,000
Useful life (h)	10,000	2000	2000
(Year)	10	8	8
Salvage value	80,000	12,500	4500
Depreciation	72	56.25	20.25
Interest (14% on average investment)	11.2	8.75	3.15
Taxes, insurance, and shelter (2.5% of initial cost per annum)	2	1.56	0.56
Fixed cost (Rs./h)	**85.20**	**66.56**	**23.96**
Field capacity (ha/h)		0.79	0.79
Labor input (man-h/ha)		1.32	1.32
Fuel consumption (L/h)		8.50	8.50
Water applied (L/h)		6245	0
Labor cost @ Rs 125/h		165	165
Repair & maintenance	80	62.50	22.50
Fuel cost (diesel) Rs. 85/L		722.50	722.50
Lubrication cost (15% of fuel cost)	108.38	-	-
Water cost @ 0.25/L		1561.25	0
Variable cost (Rs./h)		**2619.62**	**1018.375**
Total operational cost (Rs./h)		**2686.18**	**1042.3375**

4. Summary

The soil moisture deficit in the soil at wheat sowing time is the major constraint for good seed germination, and ultimately crop yield in the Pothwar region of Pakistan. The water seed drill was designed and developed at Koont research farm to fulfil the soil moisture deficit in the field at the time of sowing. The water seed drill is a combination of a water application system and the seed drill. It drops water into the seed-sowing furrow from a water tank mounted at the back of a tractor. The water flow can be controlled by a main valve at the tank, and water injectors can be used at each furrow. The water seed drill was tested at Koont Research Farm, PMAS Arid Agriculture University, Rawalpindi, Pakistan. The wheat was sown with a water seed drill and a conventional seed drill. An area of 6.58 hectares (16.25 acres) was divided in 13 plots of 0.5 ha (45 m $\times$ 40 m) each. 12 were sown with a water seed drill, and the 13th by the conventional method. The sowing operation was performed with a forward speed of 4.25 km/h and a maximum water flow rate (90, 70, and 50 mL/s), based on the existing moisture content in the soil, while the conventional plot was sown with the same speed, but with no water application. The data collected during the experiment were moisture content, seed germination, plant tillering, and wheat yield. The operation of the water seed drill gave 85% more moisture, and had a significant effect on the germination count and number of tillers, and ultimately on wheat yield. The germination count, number of tillers, and wheat yield of plots sown with the water seed drill was 95 % and 115% higher, when compared to that sown with the conventional seed drill. The water seed drill helped in advancing wheat sowing, ensuring the timely sowing of the crop in the absence of rainfall, especially in rainfed regions, and promoted drill sowing. The total investment cost with the water seed drill was 2.77 times more than the conventional seed drill. However, the wheat cost produced with the water seed drill was 2.15 times (49,000 Rs./ha) more than that of the conventional seed drill. The wheat sowing with the water seed drill led to Rs. 1561.25/ha more than that of the conventional seed drill.

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