SURFACE DRAINAGE MANAGEMENT FOR PROFITABLE SESAME CULTIVATION IN A HUMID SUBTROPIC ENVIRONMENT

Abstract

Besides drought, the most detrimental abiotic factor that impacts sesame production is water-logging. Drainage may remove surplus moisture from the ground, enhancing plant root development, plants stand, and consequently results in higher seed yield. To find out optimum drain spacing for sesame, a study was undertaken at four sesame growing areas of Bangladesh, during two consecutive years (2020 and 2021). Control (regular flat ground, no special drain) (T1), 200 cm wide beds and then a 30 cm drain (10 cm depth) (T2), 150 cm wide beds and then a 30 cm drain (T3), and 100 cm wide beds and then a 30 cm drain (T4), were the drainage treatments. Binatil-2 (V1), Binatil-3 (V2), and Binatil-4 (V3) were the test varieties. Sesame beds with a 30 cm drain and a width of 100 cm (T4) produced the best seed output. However, from an economic standpoint, a bed that is 150 cm broad and has a 30 cm drain between the beds (T3) is the best since it has the highest BCR (1.43) and net profit. Hence, a 150 cm broad bed with a 30 cm drain between the beds is recommended for profitable sesame cultivation in the studied areas. The results can also be extended for the similar soil and climatic areas.

Keywords: Sesame, Water-logging, Drainage, Drain spacing, BCR, Bangladesh.

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I. INTRODUCTION

Sesame is perhaps one of the earliest oilseed crop recognized and used by man (Weiss, 1983).Sesame seed oil is a nutrient-dense source. Additionally, sesame seeds provide a host of health advantages, including the capacity to strengthen bones, alleviate male infertility, enhance heart health, decrease blood pressure, and shield against cancer and diabetes (Staughton, 2021).

One of the important oilseed crops grown in Bangladesh's Kharif-1 season (mid-February to early June) is sesame. The sesame crop is significantly impacted by the occasionally intense rainfall that began in April due to the conditions brought on by global climate change. The national average yield of sesame is 0.93 t/ha (BBS, 2020), which is low as the cultivars are sensitive to water-logging. That's why sesame is only grown in a small portion of Bangladesh. A significant sum of foreign money is spent on the importation of oil to meet the demand for it across the whole nation. Focus should be placed on promoting high yielding cultivars using a variety of modern management techniques with a focus on water-logging in order to increase sesame output (Sarkar et al., 2016; Ali, 2017; Wang et al., 2016).

The delicate sesame crop can suffer large losses in plant numbers and seed output even after brief periods of water-logging (Bennet, 1995). Therefore, in regions where rain-water pools for a long time due to improper drainage, there is a significant loss in sesame output (Ali, 2017). Water-logging lowers soil N mineralization rates and encourages soil nitrogen (N) loss through denitrification, nitrate leaching, and runoff (Kopyra&Gwó, 2004; Haddad et al., 2013; Pengthamkeerati et al., 2006). Adjusting management practices (e.g., early or late planting; use of waterlogged-tolerant crop varieties, and cover crops); adaptive nutrient management practices (e.g., enhanced efficiency fertilizers, rescue N applications); changing the application rate, timing, and placement; and use of adaptive water management practices (e.g., improving drainage, planting in raised-bed) are potential management practices that could reduce crop failure and N-losses from the crop field due to water-logging (Dawar et al., 2011; Kaur et al., 2020a; Kaur et al., 2020b).These methods can be combined or used alone to decrease N-losses and increase yield.

According to studies by Huang et al. (1994), Mutava et al. (2015), and Oosterhuis et al. (1990), the water-logging damage lowers photosynthesis, perhaps as a result of stomatal closure, abscisic acid (ABA), ethylene, and active oxygen species generation (Jackson et al., 1988). Jackson and Ram (2003) noted that wet plants' photosynthesis was CO_2 restricted. Instead of being a response to low leaf-water potential, the restricted stomatal termination was a response to water-logging to prevent leaf-water shortages and wilting. The stomatal closure also reduces the amount of CO_2 that can enter plant cells, which causes a buildup of oxygen free radicals. Reactive oxygen species like superoxide (O_2), singlet oxygen (1/2 O_2), hydrogen peroxide (H_2O_2), and hydroxyl radicals (OH) produced in chloroplasts during the electron transport along the electron chain are more prevalent in waterlogged conditions, which causes oxidative stress in plants (Jackson & Colmer, 2005; Subbaiah & Sachs, 2003; Zheng et al., 2009). Sesame generated a potential yield on rich and well-drained soils, according to Amend et al. (2009). Sesame yield loss due to water-logging is a significant problem; hence improved drainage is essential for increased output.

Climate, factors that affect the amount of water entering the soil, factors that affect the amount of water moving through or over the surface of the soil, frequency of extreme precipitation events, and multiple wet-days are some of the factors that can cause soil water-logging in the plant-rooting zone (Kunkel, 2003). However, a number of variables, such as the soil's characteristics, the slope of the land, the spacing between drains (surface or subsurface), the depth of the drain, etc., affect how water drains from the root zone (or crop field)(Ali, 2011).

Drainage may assist remove surplus moisture from the soil, promoting better plant growth and greater agricultural yields (Blevins et al., 1996; Nelson et al., 2012). Subsurface drainage technology is used extensively to improve drainage in waterlogged soils (Sharma et al., 2016; Nelson et al., 2012). But it is expensive and troublesome for maintenance. That's why surface drainage is preferred under normal crop cultivation (Ali, 2011), specially in developing countries where initial investment is a factor for the small-holder farmers.

The response of subsurface drainage spacing in removing excess water is available in the literature, but the information regarding surface drainage is meager. Aslam et al. (2015) investigated three different planting techniques for drainage management in sesame cultivation. The planting techniques were: flat sowing with 0.45 m apart rows, ridge sowing with 0.45 m apart beds, 0.90 m apart bed (i.e. 0.60 m wide beds with 0.30 m furrow between the beds). They found that bed planting at 0.90 m apart bed produced maximum seed yield followed by ridge planting.

The response of sesame plant to soil-moisture regimes or water-logging is well documented in the literature, but the study regarding response to different surface drain spacing is scarce. Considering the above situation, the present experiment was undertaken to study the effect of different drainage spacing on sesame yield at different sesame growing areas of Bangladesh with a view to find out the best/economic drain spacing.

II. MATERIALS AND METHODS

1. **Experimental Sites**: The experiment was carried out at BINA HQ, Mymensingh (24.7245054, 90.4289949); BINA Sub-station, Magura (23.4849216, 89.3993218); BINA Sub-station, Ishwardi (24.1235073, 89.0793019); and Farmer's field, Sathia, Pabna (24.0555381, 89.5404578) during consecutive two years of Kharif season of 2020 and 2021.

2. **Soil and Climate**

   - **Mymensingh:** The land utilized for the experiment is a non-calcareous dark grey floodplain soil type called Sonatola series found in Old Brahmaputra Alluvial Tract 13. The majorities of the soils in the area are clay and silt loams to silty clay loams on the ridges. Dark Grey Floodplain soil is a common form of general soil. The topsoil is somewhat acidic but the subsoil is neutral in response; organic matter concentration is low on the ridges and moderate in the basins (BBS, 2021). The general fertility rate is low. A silty loam with a pH of 6.43 and a moderate amount of organic matter made up the experimental soil. The experimental location is located in the sub-tropical zone, which is marked by high temperatures, high levels of humidity, and significant amounts of rainfall with sporadic gusty winds. The average temperature, rainfall and relative humidity of the last 25 years (1991–2016) of this region from December to May are 23.6^{0}C, 105.78 mm and 77.6%, respectively.

- **BINA Sub-station, Magura:** On the higher portions of floodplain ridges, there is a general pattern of olive-brown silt loams and silty clay loams, and dark grey, mottled brown, mostly clay soils on ridge sites and in basins. Most ridge soils are completely calcareous. The two most common general soil types are calcareous dark grey floodplain soils and calcareous brown floodplain soils. The amount of organic matter is low in brown ridge soils and greater in dark grey soils. In response, soils have a mild alkaline pH. The general level of fertility is low (BBS, 2021). We used silty-loam soil for our experiment.

- **BINA Sub-station, Ishwardi:** According to Shil et al. (2016), the site was distinguished by high and medium high lands, as well as a complex terrain of broad and narrow ridges and basins inside the high Ganges river flood plain. The typical soil type for flood plains is calcareous dark grey to calcareous brown soil. Brown ridge soils are deficient in organic matter, whereas dark grey soils are rich in it. The general degree of fertility is medium, with the top soils being mildly acidic to mildly alkaline and the sub-soils being predominantly mildly alkaline in response (FRG, 2012).

- **Farmer's field, Sathia, Pabna:** On the ridges, the soils are silt loams and silty clay loams; on lower sites, silty clay loams to heavy clays. Calcareous Dark Grey and Calcareous Brown Floodplain soils make up the majority of general soil types. The amount of organic matter is low on the hills and moderate in the basins (BBS, 2021). Silty loam soil with a medium general fertility level made up the trial field's soil type.

3. **Treatments and Design:** The drainage treatments were as follows: **T1** = Control (regular flat land, no special drain); **T2** = 200 cm wide beds with a 30 cm drain (10 cm depth) between the beds; **T3** = 150 cm wide beds with a 30 cm drain (10 cm depth) between the beds; and **T4** = 100 cm wide beds with a 30 cm drain (10 cm depth) between the beds.
   V1 = Binatil-2, **V2** = Binatil-3, and **V3** = Binatil-4 were the test cultivar types. Three replications were used in the RCBD experimental design. The primary plot was 7 m by 5 m.

4. **Rainfall Distribution during Crop Growing Period:** Fig.1 shows the pattern of rainfall from March to May, the experimental period. Rainfall of 457 mm fell in Mymensingh, particularly during the sesame plant's vegetative and blooming periods. Additionally, a powerful storm struck during the 2020 pod filling season. In 2021, rainfall totals of 422 mm, 133 mm, and 149 mm were recorded in Mymensingh, Magura, and Ishwardi, respectively, during the sesame plant's blooming and pod-formation periods.

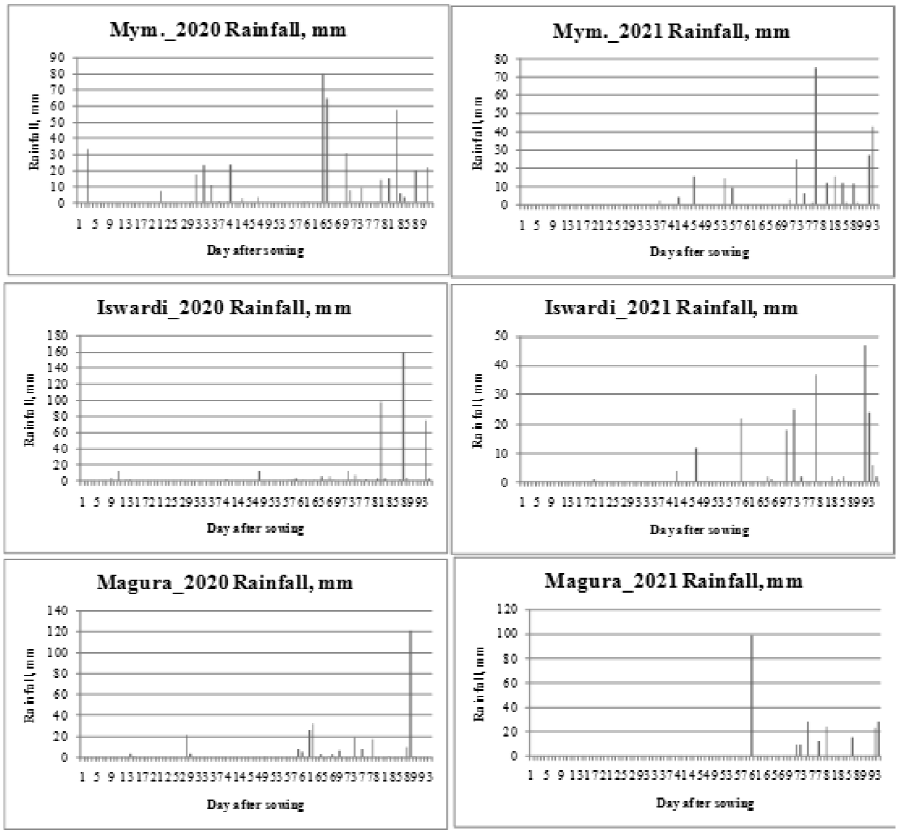

Figure 1: The Rainfall Distribution during the Experimental Period at Mymensingh, Magura and Ishwardi (Pabna)

5. **Statistical Analysis:** To determine the significance of differences between drainage treatments and sesame cultivars across four sites, the yield data and yield-attributing variables for the field experiment were statistically examined. The International Rice Research Institute (IRRI)'s "STAR" program (version 2.0.1) (IRRI, 2014) was used to statistically evaluate the data acquired for various factors. The F-test was used to calculate the means and analyze variance (ANOVA) for all parameters. The least significant difference (LSD) test was used to examine the significance of the difference between the two means at the 5% level of probability (Gomez and Gomez, 1984).

6. **Economic Analysis:** For analytical purposes, the whole cost of production was taken into account, and the cost items were divided into the following heads:

   - **Operating Expenses:** The employment of power tillers, the cost of seed, fertilizer, pesticide, irrigation application, and land usage costs are all included in operating costs. Bed preparation, planting, weeding, and thinning, pesticide application, harvesting, hauling, threshing, and cleaning are all tasks that involve human work. The cost of land usage was calculated using the land's seasonal rental value or lease value.

- **Interest on working capital:** Since all expenditures are not accelerated at the beginning or at any other set point, the working resources really represent the average operational expenses over the term. The expenses were incurred over the whole production phase. The formula shown below was used to assess interest on operating costs (I_{oc}) (Haque 2000; Ali et al. 2007):
  I_{oc}= (Operating capital / 2) × interest rate×time period................ (1)

  Total cost: Running costs plus interest on running costs equal total cost.
  Gross return (or total benefit): The entire quantity of product and by-product was multiplied by each of their individual market prices to determine the per-hectare gross return.
  Net profit (NP): The NP was determined as follows: NP = Gross Return- Total Cost
  Benefit cost ratio (BCR): The BCR was figured up as follows:
  BCR = Total benefit per hectare / Total cost per hectare................ (2)

III. THE FINDINGS AND DISCUSSION

1. **For the year 2020:** Table 1 provides a summary of the average effects of drainage treatments and cultivars on sesame seed yield. On seed yield, the drainage treatments had a noticeable impact. Among the four locations, T4 (100 cm broad beds with a 30 cm drain between them) generated the highest average yield (1103 kg/ha), followed by T3 (150 cm broad bed), while T1 (regular flat land with no special drain) produced the lowest (530 kg/ha). Except for Magura, the yield of treatments T4 and T3 is statistically comparable. Except for BINA Sub-station, Ishwardi, the cultivars' seed yields significantly varied between localities. Following V1 (Binatil-2) and V2 (Binatil-3), cultivar V3 (Binatil-4) generated the highest average yield (939 kg/ha).

Table 1: The Average Influence of Drainage Practices and Cultivars on Sesame Cultivars' Seed Yields (2020)

Treatment	Seed yield (kg per hectare)				
	Location-1 (Mymensingh)	**Location-2 (Magura)**	**Location-3 (Ishwardi)**	**Location-4(Sathia, Pabna)**	**Average over Locations**
$T_{1\ (No\ bed\ formation)}$	489 b	490 c	585 c	557 c	530 c
$T_{2(200\ cm\ wide\ bed)}$	914 a	987 b	995 b	912 b	952 b
$T_{3\ (150\ cm\ wide\ bed)}$	1099 a	915 b	1055 ab	1058 a	1032 ab
$T_{4\ (100\ cm\ wide\ bed)}$	1105 a	1089 a	1128 a	1089 a	1103 a
LSD $_{(0.05)}$	S	S	S	S	S
Cultivars					
$V_{1(Binatil-2)}$	936 a	819 b	848	823 b	857
$V_{2\ (Binatil-3)}$	968 a	845 b	949	902 ab	916
$V_{3\ (Binatil-4)}$	801 b	945 a	1025	987 a	939
LSD $_{(0.05)}$	S	S	NS	S	NS

Table 2 displays the interactions between drainage practices and cultivars that affect sesame seed output. The effect of treatments is statistically insignificant for all cultivars at

Mymensingh, Ishwardi, and Sathia (Pabna) locations, but significant at Magura location. This may be due to the rainfall variation (Fig. 1) and soil conditions.

When averaged over locations (Table 3), Binatil-4 produced the highest seed yield of 1233 Kg/ha and 1067 Kg/ha for drainage treatment T_3 (150 cm bed) and T_4 (100 cm bed), respectively followed by Binatil-3 and Binatil-2. But in flat land (control), yield was minimum and it was 574 K/ha, 546 Kg/ha and 472 Kg/ha, respectively for Binatil-2, Binatil-4 and Binatil-3.

Table 2: Effects of Cultivars and Drainage Practices in Combination on Sesame Seed Production.

Location	Treatment / Variety	T_1 (Flat land)	T_2 (200 cm bed)	T_3 (150 cm bed)	T_4 (100 cm bed)
Mymensingh	$V_{1 (Binatil-2)}$	586	1011	1152	995
	$V_{2 (Binatil-3)}$	445	1014	1165	1250
	$V_{3 (Binatil-4)}$	437	718	979	1070
	LSD $_{(0.05)}$	NS	NS	NS	NS
Magura	$V_{1 (Binatil-2)}$	525 a	896 b	929 a	928 b
	$V_{2 (Binatil-3)}$	505 a	960 b	893 a	1025 b
	$V_{3 (Binatil-4)}$	440 a	1104 a	922 a	1315 a
	LSD $_{(0.05)}$	S	S	S	S
Ishwardi	$V_{1 (Binatil-2)}$	602	805	946	1040
	$V_{2 (Binatil-3)}$	632	1082	1039	1042
	$V_{3 (Binatil-4)}$	520	1097	1481	1301
	LSD $_{(0.05)}$	NS	NS	NS	NS
Sathia Pabna	$V_{1 (Binatil-2)}$	581	785	920	1007
	$V_{2 (Binatil-3)}$	600	928	1068	1012
	$V_{3 (Binatil-4)}$	491	1022	1187	1247
	LSD $_{(0.05)}$	NS	NS	NS	NS
Average over Locations	$V_{1 (Binatil-2)}$	574	874	987	992
	$V_{2 (Binatil-3)}$	546	996	1041	1082
	$V_{3 (Binatil-4)}$	472	985	1067	1233

2. **For the Year 2021:** Table 3 provides a summary of the average effects of drainage treatments and cultivars on sesame yield. At every location, with the exception of Magura, the drainage treatments showed a significant impact on seed yield. For all locations, the highest yield was found in T_4 (100 cm broad beds with a 30 cm drain between them) followed by T_3 (150 cm wide bed) and T_2 (200 cm wide bed) except Magura location. The conventional treatment T_1 (flat land, no drain) created the lowest seed yield at all locations. In case of average yield, similar trend was also observed, i.e.

T4>T3>T2>T1. With the exception of BINA sub-station, Ishwardi, the yield of treatments T4 and T3 is statistically comparable. At every location, the cultivars had a noticeable disparity in seed output. Following V1 (Binatil-2) and V2 (Binatil-3), cultivar V3 (Binatil-4) generated the highest average yield (904 kg/ha).

Table 3: The Average Effects of Drainage Practices and Cultivars on Sesame Cultivar Production in 2021

Treatment	Seed yield (kg per hectare)				
	Location-1 (Mymensingh)	**Location-2 (Magura)**	**Location-3 (Ishwardi)**	**Location-4 (Baghail, Ishwardi)**	**Average over locations**
T_1 (No bed formation)	570 b	874	839 b	753 c	759 c
T_2(200 cm wide bed)	839 ab	1002	903 ab	822 bc	891 ab
T_3 (150 cm wide bed)	823 ab	954	897 b	874 bc	887 bc
T_4 (100 cm wide bed)	1006 a	1206	966 a	910 a	1022 a
LSD $_{(0.05)}$	S	NS	S	S	S
Cultivars					
V_1(Binatil-2)	644 b	989	1015 a	922 a	892
V_2 (Binatil-3)	871 a	951	862 b	808 b	873
V_3 (Binatil-4)	914 a	1087	826 b	789 b	904
LSD $_{(0.05)}$	S	NS	NS	S	NS

The interaction of treatment and variety had no discernible impact (Table 4). For every site, the interaction effects are negligible. When averaged over locations, it is revealed that V_2 (Binatil-3) obtained the maximum average seed yield (1040 kg/ha) in T_4 (100 cm bed) followed by V_1 (Binatil-2) and V_3 (Binatil-4).

3. **Profitability:** Location-wise and average benefit-cost ratio (BCR), net income and percent yield increase over control are presented in Table 5. For all locations, the percent yield increase over control (Flat land) was the highest in treatment T4.

The mean BCR (average over locations and years) and net income are tabulated in Table 5. Net income from the treatment T3 and T4 are almost same, and the BCR is slightly higher in T3. Thus, the treatment T3, i.e. 150 cm drain spacing can be recommended for the studied areas.

Table 4: Interaction Effects of Drainage Treatments and Cultivars on Seed Yield of Sesame.

Location	Treatment / Variety	T_1 (Flat land)	T_2 (200 cm bed)	T_3 (150 cm bed)	T_4 (100 cm bed)
Mymensingh	V_1 (Binatil-2)	461	641	637	836
	V_2 (Binatil-3)	506	927	958	1095
	V_3 (Binatil-4)	742	949	875	1089
	LSD (0.05)	NS	NS	NS	NS
Magura	V_1 (Binatil-2)	789	1019	932	1214
	V_2 (Binatil-3)	869	959	821	1153
	V_3 (Binatil-4)	965	1026	1107	1250
	LSD (0.05)	NS	NS	NS	NS
Ishwardi	V_1 (Binatil-2)	961	992	1010	1097
	V_2 (Binatil-3)	796	850	856	946
	V_3 (Binatil-4)	760	867	824	854
	LSD (0.05)	NS	NS	NS	NS
Sathia, Pabna	V_1 (Binatil-2)	908	847	925	1009
	V_2 (Binatil-3)	663	790	813	965
	V_3 (Binatil-4)	688	829	882	756
	LSD (0.05)	NS	NS	NS	NS
Average over Location	V_1 (Binatil-2)	780	875	876	1039
	V_2 (Binatil-3)	708	882	862	1040
	V_3 (Binatil-4)	789	918	922	987

Table 5: Location-wise yield, net income, BCR and percent yield increase during experiment period of sesame (average of 2 yrs).

Location	Treatment	Yield (kg/ha)	Net Income ($/ha)	BCR	Yield Increased (%)
Mymensingh	T_1 (Flat land)	509	8	1.02	-
	T_2 (200 cm bed)	873	174	1.34	71
	T_3 (150 cm bed)	1010	261	1.49	98
	T_4 (100 cm bed)	1080	253	1.42	112
Magura (Sub-station)	T_1 (Flat land)	659	121	1.29	-
	T_2 (200 cm bed)	990	267	1.52	50
	T_3 (150 cm bed)	933	200	1.37	41
	T_4 (100 cm bed)	1110	276	1.46	68
Ishwardi (Sub-station)	T_1 (Flat land)	707	138	1.32	-
	T_2 (200 cm bed)	941	228	1.44	33
	T_3 (150 cm bed)	974	232	1.43	38
	T_4 (100 cm bed)	1052	230	1.38	49
Farmar's Field, Kushtia and Pabna	T_1 (Flat land)	650	92	1.22	-
	T_2 (200 cm bed)	853	159	1.31	31
	T_3 (150 cm bed)	962	223	1.41	48
	T_4 (100 cm bed)	978	172	1.29	51
Mean over Locations	T_1 (Flat land)	631	90	1.21	-
	T_2 (200 cm bed)	914	207	1.40	45
	T_3 (150 cm bed)	969	229	1.43	54
	T_4 (100 cm bed)	1055	233	1.39	67

Note: 1 $ = 85 BDT (at the harvesting period).

4. **Pooled analysis:** Pooled analyses of the data (over locations and years) were performed. The mean seed yields of sesame are tabulated in Table 6 the maximum seed yield was produced under T_4 treatment tracked by T_3, and the yields are statistically different.

Table 6: Combined Result of Drainage Formation Over Locations, Years and Varieties on Seed Yield of Sesame.

Treatment	Yield, Kg/ha
T_1 (No bed formation)	645 d
T_{2}(200 cm wide bed)	913 c
T_3 (150 cm wide bed)	963 b
T_4 (100 cm wide bed)	1064 a
LSD $_{(0.05)}$	S

The interaction results of cultivars with drainage management (under pooled analysis) are abridged in Table 7 although demonstrated statistically in significant variation, the cultivar V3 under treatment T4 produced the highest yield followed by V2T4.

Table 7: Combined effects of varieties and drainage treatments over years and locations on seed yield of sesame.

Treatment / Variety	T_1 (Flat land)	T_2 (200 cm bed)	T_3 (150 cm bed)	T_4 (100 cm bed)
V_1(Binatil-2)	677	874	932	1021
V_2 (Binatil-3)	627	930	954	1061
V_3 (Binatil-4)	630	933	1004	**1110**
LSD $_{(0.05)}$	NS	NS	NS	NS

IV. CONCLUSION

Field trials were demonstrated for two successive years at different (four) locations of Bangladesh. The 100 cm broad beds with a 30 cm drain among them produced the maximum yield follow by the 150 cm broad bed with a 30 cm drain between the beds. In terms of net profit, 150 cm broad bed along with a 30 cm drain among them produced the maximum net return followed by 100 cm thick beds along with a 30 cm drain among them the beds. Thus, for profitable sesame cultivation, 150 cm bed along with 30 cm drain among them can be suggested as the best practice at major sesame producing regions of Bangladesh.

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