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

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Abstract

Besides drought, water-logging is the most damaging abiotic stress that affects sesame production. Drainage can remove excess water from the soil, which improves plant root growth, plant stands, 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). The imposed drainage treatments were: Control (normal flat land, no special drain) (T_1), 200 cm wide beds and then 30 cm drain (10 cm depth) (T2), 150 cm wide beds and then 30 cm drain (T_3), 100 cm wide beds and then 30 cm drain (T_4). The test varieties were: Binatil-2 (V_1), Binatil-3 (V_2) and Binatil-4 (V_3). The highest seed yield of sesame was obtained in 100 cm wide beds accompanied by 30 cm drain (T_1). But from the economic point of view, 150 cm wide bed accompanied by 30 cm drain between the beds (T_3) is the best for its maximum net profit and BCR (1.43). Hence, 150 cm wide bed accompanied by 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, waterlogging, Drainage, Drain spacing, BCR, Bangladesh

Introduction

Sesame is perhaps one of the earliest oilseed crop recognized and used by man (Weiss, 1983). Sesame seed oil is a rich source of nutrients. In addition, sesame seeds have many health benefits including ability to improve heart health, lower blood pressure, build strong bones, treat male infertility, and prevent cancer and diabetes (Staughton, 2021).

Sesame is one of the major oilseed crops that are cultivated during the Kharif-1 season (Mid February to June) in Bangladesh. Due to global climate change condition, sometimes heavy rainfall started from the beginning of April, which affects the sesame crop to a great extent. The cultivated area of sesame in Bangladesh is low. The reason is low yield (which is about 0.93 t/ha, national average) (BBS, 2020) and sensitivity of the cultivars to water-logging.

To satisfy the countrywide demand of oil, an enormous amount of overseas currency is disbursed to import oil. With the purpose of intensification the production of sesame, emphasis should be given to promote high yielding cultivars applying various up-to-date management practices with distinct attention to water-logging (Sarkar et al., 2016; Wang et al., 2016; Ali, 2017).

Sesame crop is sensitive to water-logging even short periods of water-logging may results in significant reductions in plant numbers and seed yield (Bennet, 1995). Hence, lack of proper drainage system caused major reduction in sesame yield in areas where rain water stands for long periods of time (Ali, 2017). Waterlogging promotes soil nitrogen (N) loss through processes such as denitrification, nitrate leaching and runoff (Kopyra & Gwó, 2004) as well as reduces soil N mineralization rates (Haddad et al., 2013; Pengthamkeerati et al., 2006). Potential management practices for reduction of crop production and N-losses due to waterlogging may include 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); altering the application rate, timing, and placement (Dawar et al., 2011); use of adaptive water management practices (e.g., improving drainage, raised bed planting) (Kaur et al., 2020a); or use of precision agriculture technology (Kaur et al., 2020b).
These technologies may be used alone *or* in grouping to synergistically limit N-losses and produce potential yield.
The waterlogging injury reduces photosynthesis (Huang et al., 1994; Mutava et al., 2015; Oosterhuis et al., 1990), possibly due to stomatal closure, abscisic acid (ABA), ethylene, and active oxygen species production (Jackson et al., 1988). Jackson and Ram (2003) observed that photosynthesis was CO_2 limited in waterlogged plants. The limited stomatal termination was a reaction to waterlogging to stop leaf water shortages and wilting, instead of being a response to low leaf water potential. The stomatal closure also limits CO_2 in plant cells and consequently,

results in accumulation of oxygen free radicals. Plants suffer oxidative stress under waterlogged conditions through an increase in reactive oxygen species, such as 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 (Jackson & Colmer, 2005; Subbaiah & Sachs, 2003; Zheng et al., 2009). Amend *et al*., (2009) noted that sesame produced potential yield on fertile and well-drained soils. Damage of waterlogging is an important factor of yield loss in sesame; and hence, good drainage is crucial for its better yield.

Soil water-logging in the plant-rooting zone is influenced by several factors including climate, factors that affect the amount of water entering into the soil, the amount of water moving through or over the surface of the soil, frequency of extreme precipitation events and multiple wet days (Kunkel, 2003). On the other hand, drainage of water from the root-zone (or crop field) is influenced by several factors including soil properties, slope of the land, drain spacing (surface or subsurface), depth of drain, etc. (Ali, 2011). Drainage can remove excess water from the soil, which helps plants grow better and produce more crops (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 waterlogging 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.

2 Materials and Methods

2.1 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, Iswardi (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.

2.2 Soil and climate

Mymensingh:

The soil used for the experiment belongs to the Sonatola series of non-calcareous dark grey floodplain soil type under the Old Brahmaputra Alluvial Tract 13. Soils of the area are predominantly silt loams to silty clay loams on the ridges and clay in the basins. General soil types predominantly include Dark Grey Floodplain soil. Organic matter content is low on the ridges and moderate in the basins; topsoils are moderately acidic but subsoils neutral in reaction. General fertility level is low (BBS, 2021). The experimental soil was a silty loam having a pH value of 6.43 and moderate organic matter content. The experimental site falls under the sub-tropical zone, which is characterized by high temperature, high humidity and heavy rainfall with occasional gusty winds in the Kharif season (April – September) and less rainfall associated with moderately low temperature during the Rabi season (October – March). The average temperature, rainfall and relative humidity of the last 25 years (1991–2016) of this region from December to May are 23.6^{o}C, 105.78 mm and 77.6%, respectively.

BINA Sub-station, Magura:

There is an overall pattern of olive-brown silt loams and silty clay loams on the upper parts of floodplain ridges and dark grey, mottled brown, mainly clay soils on ridge sites and in basins. Most ridge soils are calcareous throughout. General soil types predominantly include Calcareous Dark Grey Floodplain soils and Calcareous Brown Floodplain soils. Organic matter content in brown ridge soils is low and higher in dark grey soils. Soils are slightly alkaline in reaction. General fertility level is low (BBS, 2021). Our experiment soil type was silty-loam .

BINA Sub-station, Iswardi:

The site was characterized by high and medium high lands and complex relief of broad and narrow ridges and basins under the Agro Ecological Zone (AEZ) 11 of high Ganges river flood plain (Shil *et. al.* 2016). Soil type is generally calcareous dark grey to calcareous brown flood plain soils. Organic matter is deficit in brown ridge soils but enriched in the dark grey soils. Top soils are slightly acidic to slightly alkaline and sub soils are mostly slightly alkaline in reaction and general fertility level is medium (FRG, 2012).

Farmer's field, Sathia, Pabna:

Soils of the region are silt loams and silty clay loams on the ridges and silty clay loams to heavy clays on lower sites. General soil types predominantly include Calcareous Dark Grey and Calcareous Brown Floodplain soils. Organic matter content is low in ridges and moderate in the basins. At experiment field, soil type was siltyloam with medium general fertility level (BBS, 2021).

2.3 Treatments and design

The imposed drainage treatments were: T_1 = Control (normal flat land, no special drain); T_2= 200 cm wide beds and 30 cm drain (10 cm depth) between the beds; T_3 = 150 cm wide beds and 30 cm drain (10 cm depth) between the beds; T_4= 100 cm wide beds and 30 cm drain (10 cm depth) between the beds. The test varieties were: V_1 = Binatil-2, V_2 = Binatil-3 and V_3 = Binatil-4. The experimental design was RCBD, with 3 replications. The main plot size was 7 m × 5 m.

2.4 Rainfall distribution during crop growing period

The rainfall distribution during the experimental period (March to May) is depicted in Fig. 1. A total of 457 mm rainfall was occurred specially at vegetative and flowering stages of sesame at Mymensingh. In addition, a strong storm was attacked during the pod filling period in the year of 2020. A total of 422 mm, 133 mm and 149 mm rainfall were occurred specially at flowering and pod formation stages of sesame at Mymensingh, Magura and Ishwardi, respectively in year 2021.

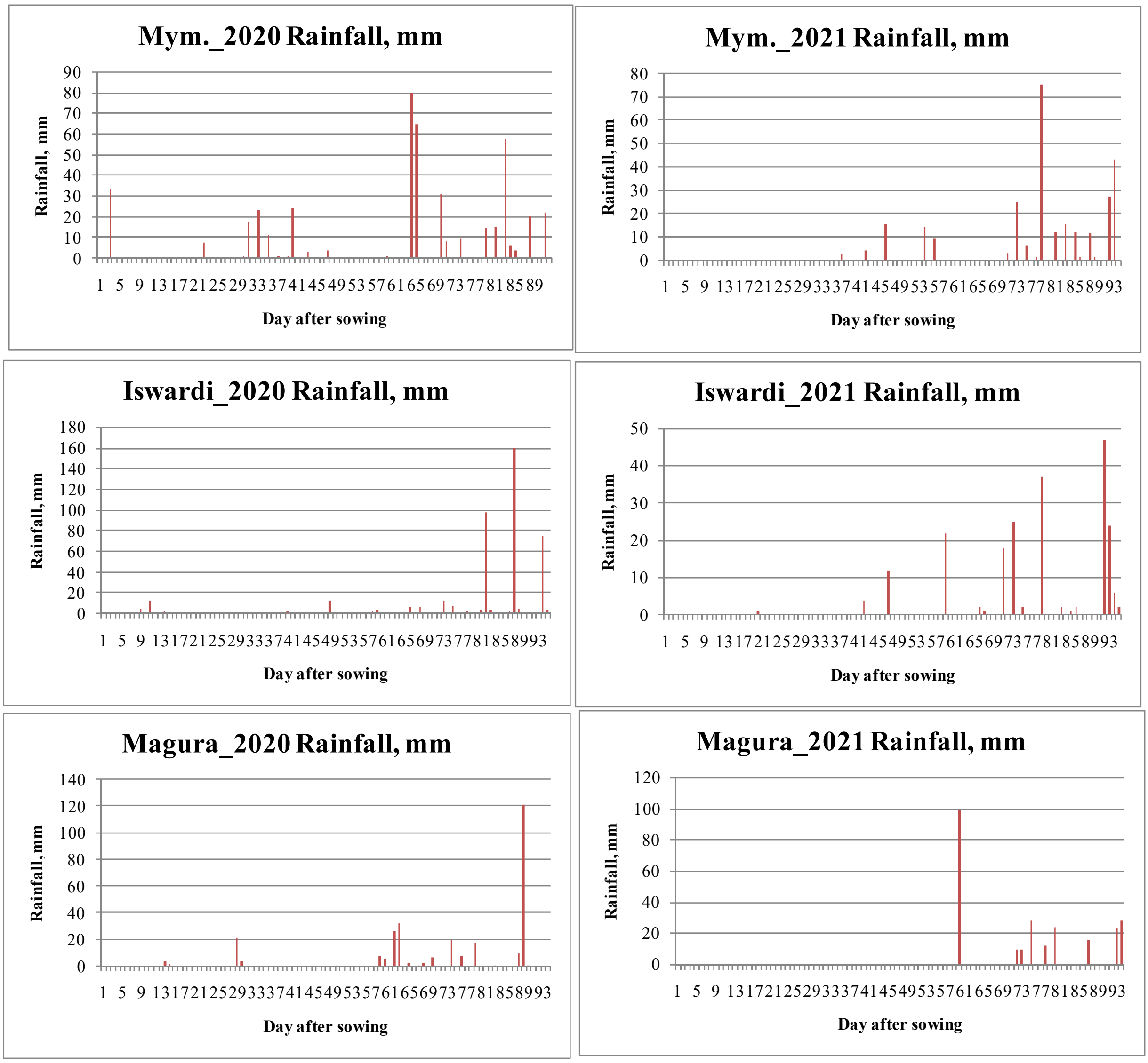

Fig. 1. The rainfall distribution during the experimental period at Mymensingh, Magura and Ishwardi (Pabna)

2.5 Statistical analysis

For the field experiment, the data attained on yield and yield attributing characteristics were statistically analyzed to find out the significance of difference among drainage treatments and sesame cultivars over four locations. The obtained data on various parameters were statistically analyzed using "STAR" software of 'International Rice Research Institute (IRRI)' (STAR, version 2.0.1) (IRRI, 2014). The mean values and analysis of variance (ANOVA) of all parameters were performed by F-test. The significance of difference between the pair of means was compared by the least significant difference (LSD) test at 5% level of probability (Gomez and Gomez, 1984).

2.6 Economic analysis

Total cost of production was considered during this analysis and the cost items were categorized as following heads for analytical advantages:

Operating cost:

Operating cost consists of cost of human labor; power tiller hiring; cost of seed, fertilizer, insecticide, irrigation application; and land use cost.

Human labor requirement consists of bed formation, sowing, weeding and thinning, insecticide spraying, harvesting, carrying, threshing and cleaning. Land use cost was estimated using seasonal rental value *or* lease value of the land used.

Interest on operating capital:

The working resources actually represent the standard operating costs above the period because all costs are not speeded at the opening or at any permanent time. The costs were incurred throughout the whole production period. Interest on operation cost was estimated by using the following formula (Haque 2000; Ali *et al.* 2007):

Interest on operating capital = (Operating capital / 2) x rate of interest x time considered ....(1)

Total cost = Operating cost + Interest on operating cost

Per hectare gross return was calculated by multiplying the total quantum of product and by- product by their separate request prices.

Net profit (NP) was calculated as: NP = Gross return – total cost

Benefit cost ratio (BCR) was calculated as:

BCR = Total benefit (per hectare) / Total cost (per hectare) ....(2)

3 Results and Discussion

3.1 For the year 2020:

The mean effects of drainage treatments and cultivars on yield of sesame are summarized in **Table 2.1**. The drainage treatments demonstrated significant effect on seed yield. Among four locations, the highest average yield (1103 kg/ha) was obtained in T_4 (100 cm wide beds and 30 cm drain between the beds) followed by T_3 (150 cm spacing), and the treatment T_1 (normal flat land, no special drain) produced the lowest (530 kg/ha). The yield of treatment T4 and T3 are statistically similar except Magura.

The cultivars showed significant difference in seed yield at all locations except BINA Sub-station, Ishwardi. The cultivar V_3 (Binatil-4) produced the highest average yield (939 kg/ha) followed by V_1 (Binatil-2) and V_2 (Binatil-3).

Table 2.1. Mean effects of drainage treatments and cultivars on seed yield of sesame cultivars (2020)

Treatment	Seed yield (kg/ha)				
	Mymensingh	**Magura**	**Ishwardi**	**Sathia, Pabna**	**Average**
T_1 (Flat land)	489 b	490 c	585 c	557 c	530 c
T_2 (200 cm bed)	914 a	987 b	995 b	912 b	952 b
T_3 (150 cm bed)	1099 a	915 b	1055 ab	1058 a	1032 ab
T_4 (100 cm bed)	1105 a	1089 a	1128 a	1089 a	1103 a
F-test at (5%)	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
F-test at (5%)			NS		NS

Note: Means with the same letter are not significantly (statistically) different at 5% probability level by Tukeys's Honest Significant Difference (THSD) test.

Interaction effects of drainage treatments and cultivars on seed yield of sesame are shown in Table 2.2. The treatment effects are 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 2.2), Binatil-4 produced the height 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-3 and Binatil-4.

Table 2.2. Interaction effects of drainage treatments and cultivars on grain 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)	586	1011	1152	995
	V_2 (Binatil-3)	445	1014	1165	1250
	V_3 (Binatil-4)	437	718	979	1070
	F-test at (5%)	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
	F-test at (5%)	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
	F-test at (5%)	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
	F-test at (5%)	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

Note: *Means with the same letter are not significantly (statistically) different at 5% probability level by Tukeys's Honest Significant Difference (THSD) test.*

3.2 For the Year 2021:

The mean effects of drainage treatments and cultivars on yield of sesame are summarized in **Table 3.1**. The drainage treatments demonstrated significant effect on seed yield at all locations except Magura. For all locations, the highest yield was obtained in T_4 (100 cm wide beds and 30 cm drain between the beds) followed by T_3 (150 cm spacing) and T_2 (200 cm spacing) except Magura location. The treatment T_1 (normal flat land, no special drain) produced the lowest seed yield at all locations. In case of average yield, similar trend was also observed, i.e. T4>T3>T2>T1. The yield of treatment T_4 and T_3 are statistically similar except BINA sub-station, Ishwardi.

The cultivars showed significant difference in seed yield at all locations. The cultivar V_3 (Binatil-4) produced the highest average yield (904 kg/ha) followed by V_1 (Binatil-2) and V_2 (Binatil-3).

Table 3.1. Mean effects of drainage treatments and cultivars on yield of sesame cultivars (2021)

Treatment	Grain yield (kg/ha)				
	Mymensingh	Magura	Ishwardi	Baghail, Ishwardi	Average
T_1 (Flat land)	570 b	874	839 b	753 c	759 c

T_2 (200 cm bed)	839 ab	1002	903 ab	822 bc	891 ab
T_3 (150 cm bed)	823 ab	954	897 b	874 bc	887 bc
T_4 (100 cm bed)	1006 a	1206	966 a	910 a	1022 a
F-test at (5%)	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
F-test at (5%)	S	NS	NS	S	NS

Note: Means with the same letter are not significantly (statistically) different at 5% probability level by Tukeys's Honest Significant Difference (THSD) test.

The interaction between treatment and variety showed insignificant effect **(Table. 3.2)**. The interaction effects are insignificant for all locations. When averaged over locations, it is revealed that V_2 (Binatil-3) produced the highest average seed yield (1040 kg/ha) in T_4 (100 cm bed) followed by V_1 (Binatil-2) and V_3 (Binatil-4).

Table 3.2. Interaction effects of drainage treatments and cultivars on grain 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
	F-test at (5%)	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
	F-test at (5%)	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
	F-test at (5%)	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
	F-test at (5%)	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

Note: Means with the same letter are not significantly (statistically) different at 5% probability level by Tukeys's Honest Significant Difference (THSD) test.

3.3 Profitability

Location-wise and average benefit cost ratio (BCR), net income and percent yield increase over control are presented in **Table 4.1**. 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 4.2**. 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 4.1. Location-wise yield, net income, BCR and % yield increase during experiment period of sesame (average of 2 yrs).

Location	Treatment	Yield (kg/ha)	Net Incime ($/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).

3.4 Pooled analysis

Pooled analyses of the data (over locations and years) were performed. The mean seed yields of sesame are tabulated in Table 5.1. The highest seed yield was produced under T4 treatment followed by T3, and the yields are statistically different.

Table 5.1. Combined effects of drainage treatments over Locations, years and cultivars on grain yield of sesame.

Treatment	Yield, Kg/ha
T_1 (Flat land and no drain)	645 d
T_2 (200 cm wide bed and 30 cm drain between beds)	913 c
T_3 (150 cm wide bed 200 cm bed and 30 cm drain between beds)	963 b
T_4 (100 cm wide bed 100 cm bed and 30 cm drain between beds)	1064 a
F-test at (5%)	S

Note: Means with the same letter are not significantly (statistically) different at 5% probability level by Tukeys's Honest Significant Difference (THSD) test.

The interaction effects of cultivars with drainage treatments (under pooled analysis) are summarized in Table 5.2. Although showed statistically insignificant difference, the cultivar V3 under treatment T4 produced the highest yield followed by V2T4.

Table 5.2. 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**
F-test at (5%)	NS	NS	NS	NS

Note: Means with the same letter are not significantly (statistically) different at 5% probability level by Tukeys's Honest Significant Difference (THSD) test.

Conclusion

Field experiments were conducted for two consecutive years at four locations of Bangladesh. The 100 cm broad beds with a 30 cm drain between them produced the maximum yield, followed by the 150 cm spacing with a 30 cm drain between the beds. In terms of net profit, 150 cm bed accompanied by 30 cm drain between beds produced the maximum net return followed by 100 cm wide beds accompanied by 30 cm drain between the beds. Thus, for profitable sesame cultivation, 150 cm bed along with 30 cm drain between beds can be suggested as the best practice at major sesame producing regions of Bangladesh.

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