



Ridge and Furrow Sowing Method with Close Spacing Reduces the Salinity Effect of Sunflower Production in the Ganges Delta

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Coastal areas of the Ganges delta require optimization of agronomic practices to reduce the salinity effect on the crop production that can support the “Bangladesh Delta plan 2100”. The present study was conducted in the *Rabi* seasons of 2018-19 and 2019-20 to determine the optimum sowing method and plant spacing of sunflower (variety Hysun 33) in the saline area of Bangladesh. Two sowing methods: flatbed sowing and ridge and furrow sowing and; three plant spacings: 40 cm × 25 cm, 50 cm × 25 cm and 60 cm × 25 cm were laid out in a randomized complete block design with three replications on a farmer’s field at Dacope, Khulna. Results showed that although method of sowing had no significant effect on the yield of sunflower the ridge and furrow sowing method reduced the soil bulk density and soil salinity and increased the soil water holding capacity and solute potential significantly. Plant spacing and planting system (interaction of sowing method × plant spacing) had significant effects on growth and yield of sunflower. Plant spacing 50 cm × 25 cm produced the highest sunflower seed (2233 kg ha⁻¹) by achieving optimum plant population to utilize the resource. Planting system: ridge and furrow sowing at 50 cm × 25 cm spacing had the lowest soil salinity (4.01 dS m⁻¹) and soil bulk density (0.90 Mg m⁻³) which leads to highest solute potential (-380 KPa) and highest soil water holding capacity (21%,w/w) at 85 days after sowing of sunflower. This planting system had the highest crop growth rate (24.4 g m⁻² day⁻¹) that ultimately produced the highest grain weight per head (36 g) and seed yield (2274 kg ha⁻¹) of sunflower. Ridge and furrow sowing at 50 cm × 25 cm can be effective for achieving maximum yield of sunflower in the Ganges tidal floodplain of Bangladesh.

(*Key words:* Bulk density, Coastal floodplain, *Helianthus annuus*, Planting system, Polder area, Solute potentials, Wet clay soil)

The Ganges tidal floodplain of Bangladesh includes 2.86 million hectares of coastal and off-shore lands which is about 30% of the total cultivable lands of the country (BBS, 2023). The contiguous coastal zones of Southern Bangladesh and West Bengal in India have similar geomorphology, soils and agro-climatic conditions. The population of the region is about 40 million in Bangladesh and 23 million in West Bengal (Mainuddin *et al.*, 2021).

Unfavorable environment and hydrological circumstances restrict crop production in the saline

Ganges delta. The Government of Bangladesh has prioritized the coastal zone in the “Bangladesh Delta plan 2100” to increase the cropping intensity by introducing climate-resilient dry season crops like sunflower. Sunflower (*Helianthus annuus* L.) is a promising oil seed crop in the polder area of Bangladesh to increase cropping intensity and productivity. Sunflower is moderately stress tolerant and can withstand the harsh conditions of the saline zone of Bangladesh while contributing to much-needed increased oilseed production of Bangladesh (Baten *et al.*, 2015). The

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mean yield of sunflower in Bangladesh is low (1700 kg ha⁻¹) (FAO, 2022) compared to other sunflower-growing nations and the major reasons for low productivity are its cultivation in rainfed conditions with sub-optimal crop stands and planting by the flatbed line sowing method. Proper planting system helps to conserve soil moisture at the time of scant rainfall or drought and it also helps to dispose of water at the time of excessive rainfall from the field (Let *et al.*, 2016). Ridge and furrow sowing has emerged as a new method of sowing sunflower but for this method optimum plant spacing is yet to be ascertained for the salt-affected polder area. Ridge and furrow sowing may facilitate prolonged availability of soil moisture as compared to flatbed sowing method. Ridge and furrow sowing increases solar radiation interception and water use efficiency (Borger *et al.*, 2010) leading to higher achene and oil yield of sunflower as compared to the flatbed method (Pan *et al.*, 2019).

Plant spacing effects are highly influential in sunflower yield because there is no possibility of covering gaps between plants by branching or tillering (Saleem *et al.*, 2008). High plant density increases light interception for photosynthesis but as the plant density increases, the competition for light, water and nutrients between plants also increases, which result in the decrease in vegetative and reproductive plasticity of plant (Cucci *et al.*, 2017). Optimum plant spacing and ideal planting geometry increase the efficient harnessing of resources and help to achieve higher yield of sunflower.

The present study was conducted to determine the best planting system (sowing method and row spacing) of sunflower to reduce the salinity effects and increase the sunflower yield in the coastal saline area of Bangladesh. The hypothesis was that there was no significant difference in the sunflower yield due to planting system or interaction with plant spacing.



Fig. 1. Ridge and furrow sowing method

MATERIALS AND METHODS

Experiment site

Field experiments were undertaken in two consecutive *Rabi* seasons of 2018-19 and 2019-20 on a farmer's field in Tildanga, Dacope, Khulna district of Bangladesh (22°59'77" N and 89° 46'29" E, ~2-3 m above mean sea level). The climate is sub-tropical monsoon with high summer temperatures (March-June), dry and cool winters (November-February) and a rainy monsoon period (June to October) with an average annual rainfall of 1800 mm (Mondal *et al.*, 2015). During the study, the

lowest daily temperatures occurred in January (8 -10°C) and the highest daily temperatures occurred in April (35-37°C). Total rainfall during the growing season was 173 and 66 mm in the first and second years, respectively. The experimental site belongs to the Ganges Tidal Flood plain agro-ecological zone (known as AEZ 13) (BARC, 2018). The soil texture ranged from a silty clay at 0 - 30 cm depth to clay at 30 - 60 cm.

Experimental design and field management

The experiment was laid out in a randomized complete block design in three replicates using

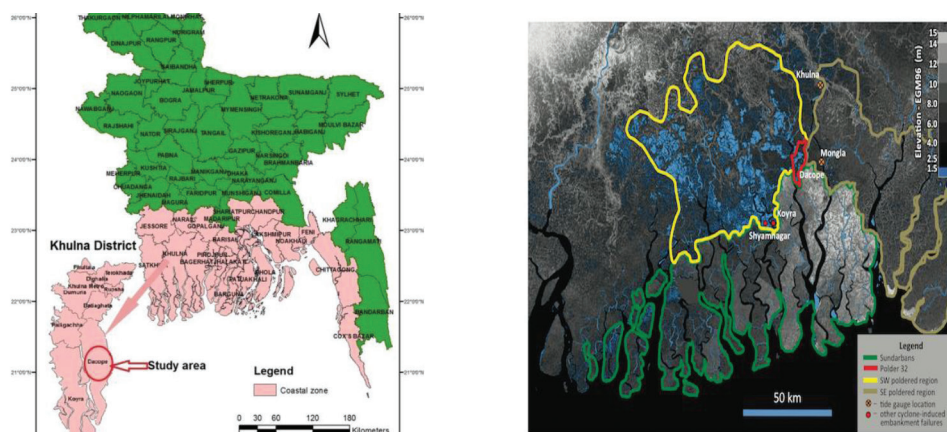


Fig. 2. Experiment site location, Polder no. 32, Dacope, Khulna, Bangladesh [Source: LGED, 2018]

a plot size of 4.0 m × 3.0 m (12 m²). Sunflower cultivar Hysun 33 was selected as the test crop. Two sowing methods *viz.*, flatbed sowing and ridge and furrow sowing and three plant spacings, 40 cm × 25 cm, 50 cm × 25 cm and 60 cm × 25 cm, were applied in factorial combination. The planting patterns involved combining two sowing methods (flat bed sowing, ridge and furrow sowing) and three row spacings (40 cm, 50 cm and 60 cm) with the same plant-to-plant spacing of 25 cm. The planting treatments were as follows: S₁ = Flat bed sowing at 40 cm × 25 cm, S₂ = Ridge and furrow sowing at 40 cm × 25 cm, S₃ = Flat bed sowing at 50 cm × 25 cm, S₄ = Ridge and furrow sowing at 50 cm × 25 cm, S₅ = Flat bed sowing at 60 cm × 25 cm and S₆ = Ridge and furrow sowing at 60 cm × 25 cm. The total number of plots were 2×6×3 = 36. Sunflower seeds were dibbled into the no-tilled wet soil (Paul *et al.*, 2020) on 21 December by making a hole with a round stick to a depth of 2-3 cm. The fertilizer was applied at 200-200-170-170-10-12 kg ha⁻¹ as urea-triple super phosphate-muriate of potash-gypsum-zinc sulphate-boric acid (BARC, 2018). All fertilizers except 75% of urea were applied at sowing by adding to a hole (5-7 cm deep) on both sides of the plant (~ 5 cm distance) along the rows, and the rest of the urea was top-dressed in equal splits during irrigation events. For pre-plant weed control, Roundup (Glyphosate 62%) was sprayed seven days before sowing, and a hand weeding was done at 25 days after sowing (DAS) (Paul *et al.*, 2020). Nitro (Cypermethrin +

Chlorpyrifos) was sprayed three times during the season to control hairy caterpillar. Irrigation water was applied by hose pipe during urea top dressing at 30, 55 and 70 DAS. Before maturity, an overhead net was set up to prevent damage to crops by birds. Physiological maturity was determined when all seeds had turned black and shiny. Ten plants were randomly selected to measure head diameter, head weight, number of filled grain per head and 1000 seed weight at harvest. The final grain yield and stalk yield was calculated per plot and then converted into kg ha⁻¹ at an adjusted moisture content of 9% (w/w).

Soil analysis

Soil bulk density was measured at 0-30 cm depth before sowing and after the harvesting of the crops. Intact soil cores (5 cm height and 4.8-5 cm in diameter) were extracted from the soil. The initial weight of the samples was measured, and then soils were dried in an oven at 105°C for about 48 h. After removing from the oven, soils were weighed again, and bulk density was calculated (Cresswell and Hamilton, 2002). Soil water content, electrical conductivity, solute potentials and bulk density were measured at 0-30 cm soil depths at different growth stages of sunflower. Before sowing, undisturbed soil at 0-15 and 15-30 depths was collected to measure soil water content at field capacity and wilting point by using a pressure plate apparatus (Eijkelkamp pF set). Measurements were made in EC_{1:5} (dS m⁻¹) extracts (a 1:5 soil:water suspension) using a

portable EC meter. The solute potential of the soil solutions was calculated by the following equation: $\Psi_s = -22580 \times EC_{1:5}/W$, where, Ψ_s is the solute potential (kPa), $EC_{1:5}$ is the electrical conductivity ($dS\ m^{-1}$) of the 1:5 soil:water extract and W is the soil water content (% w/w). This formula is based on that of Rengasamy (2010), with the additional considerations that the mix of salts in the soils of Ganges-Brahmaputra-Delta is $\sim 2/3$ NaCl and $\sim 1/3$ $MgSO_4$ (Bandyopadhyay *et al.*, 2003), and that the slopes of the lines between EC and solute potential for these two salts were as reported by Wolf *et al.* (1986).

Plant growth and yield calculation

Five representative plants were randomly selected, and marked in each plot. Then the plants for each treatment were separated into parts and then dried in a constant temperature oven at $75^\circ C$ for dry matter: root, shoot and leaf to calculate the crop growth rate. Sunflowers were harvested on 05-15 April 2019 and 01-09 April 2020 upon physiological maturity when head diameter, the number of achenes per head and biomass production were measured for the marked sunflowers corresponding to the different planting systems. The achene yield for each plot was measured after threshing and air drying and converted to $kg\ ha^{-1}$.

Statistical analysis

The average data of soil salt accumulation, plant characteristics, yield compositions of 2018-19 and 2019-20 were analyzed using Excel 2016 and all plant parameters were analyzed with two-way ANOVA using R software (Version 4.1.1). The comparison of means was tested using the least significant difference (LSD) at the 95 % confidence level.

RESULTS AND DISCUSSION

The study was conducted to assess the interactive effect of sunflower sowing method and plant spacing on soil properties and crop growth.

Soil bulk density

Soil bulk density significantly changed due to sowing method and was higher for the flatbed sowing method ($1.48\ g\ cm^{-3}$) than ridge and furrow sowing

method ($1.01\ Mg\ m^{-3}$). Plant spacing had no significant effect on soil bulk density (Table 1). The planting system and plant spacing interaction significantly affected the soil bulk density. Ridge and furrow sowing at $50\ cm \times 25\ cm$ showed the lowest soil bulk density ($0.90\ Mg\ m^{-3}$) (Fig. 3). Soil bulk density was negatively correlated to yield and yield contributing characters (Table 3) (Fig. 8A). Bulk density values greater than $1.47\ Mg\ m^{-3}$ are said to restrict root growth (Hunt *et al.*, 1992) in the wet clay soil. In case of flatbed sowing, the bulk density was higher and may have restricted the root growth of sunflower. The significantly lower BD for the ridge and furrow sowing method than flatbed can be attributed to the soil loosening required to form a furrow (Chen *et al.*, 2015). There was no interaction of sowing method and planting system.

Soil salinity

Soil salinity or the electrical conductivity significantly changed due to sowing method, being higher with the flatbed sowing method ($6.37\ dS\ m^{-1}$) than ridge and furrow sowing method ($4.70\ dS\ m^{-1}$). Plant spacing had no significant effect on soil electrical conductivity (Table 1). Plant spacing $50\ cm \times 25\ cm$ of ridge and furrow sowing method had the lowest soil salinity 2.8, 3.2 and $4.01\ dS\ m^{-1}$ at 45, 65 and 85 DAS respectively. Soil salinity was negatively correlated to yield and yield contributing characters (Table 3) (Fig. 8B). Raised beds have been regarded as an effective option for reducing waterlogging and soil salinity in landscapes with shallow saline groundwater (Bakker *et al.*, 2010). Devkota *et al.* (2015 a,b) reported that soil salinity was significantly lower in the furrow compared to conventional planting. At each time of sampling, sowing ridge and furrow sowing showed lower soil salinity than flatbed sowing.

Soil water content

Soil water content was significantly affected by sowing method and was higher in the ridge and furrow sowing method (36.2%) than flatbed sowing method (29.3%) (Table 1). Soil water content did not significantly differ due to plant spacing but the ridge and furrow sowing at $50\ cm \times 25\ cm$ (S_4) planting system had the highest soil water content at different growth periods of sunflower. Water stress at 65 DAS and 85 DAS were seen in the flatbed sowing method irrespective of spacing.

Table 1. Soil characters and crop growth rate at 65 to 85 DAS of sunflower as influenced by sowing method and plant spacing under saline condition

Particulars	Soil bulk density (Mg m ⁻³)	Soil salinity EC _{1:5} (dS m ⁻¹)	Soil water content % (w/w)	Solute potential (kPa)	Crop growth rate (g m ⁻² day ⁻¹)
Sowing method					
Flatbed	1.48	6.37	29.3	-591	16.6
Ridge and furrow	1.01	4.7	36.2	-479	20.9
SEm±	0.225	0.835	3.42	64.8	1.15
C.D. (P=0.05)	0.61	2.26	9.27	175.6	3.12
LSD and Significance level	0.3*	1.67*	6.84**	129.6**	2.3*
Plant spacing					
40 cm × 25 cm	1.26	5.50	32.5	-556	14.10
50 cm × 25 cm	1.20	5.21	34.6	-459	23.82
60 cm × 25 cm	1.29	5.90	31.2	-590	18.32
SEm±	0.03	0.24	1.20	48.1	3.44
C.D. (P=0.05)	0.05	0.38	1.88	75.6	5.41
LSD and Significance level	NS	NS	NS	129.6**	2.3***

***, ** and * denote significant at 0.001, 0.01 and 0.05 levels of probability, respectively; NS = statistically not significant at 0.05 level of probability

Plant spacing of 50 cm × 25 cm is optimum to secure the highest soil water content (25% (w/w) at 65 DAS and 21% (w/w) at 85 DAS (Fig.4). Soil water content was positively correlated to yield contributing characters (Table 3) (Fig. 8C). Sunflower yield is generally more sensitive to water stress at flowering than seedling and bud initiation stages (Unger, 1983). However, the effects of water stress in the present experiments may have not

been most severe at flowering. For the ridge and furrow sowing method the water holding capacity increased because of soil physical change due to the process of furrow making. Similar findings were found and stated by Sun *et al.* (2017).

Solute potential

Solute potential significantly increased in ridge

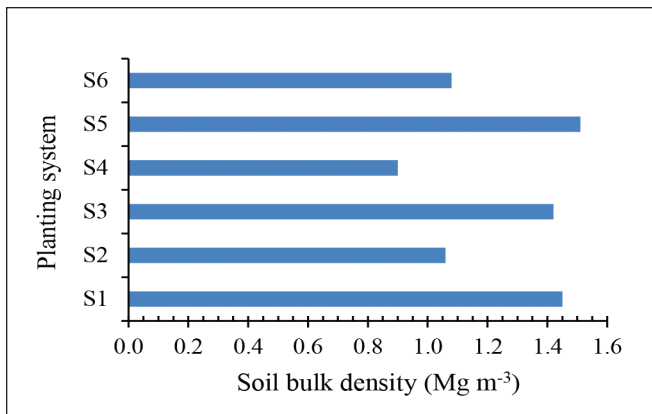


Fig. 3. Soil bulk density (0-30 cm) under different planting systems

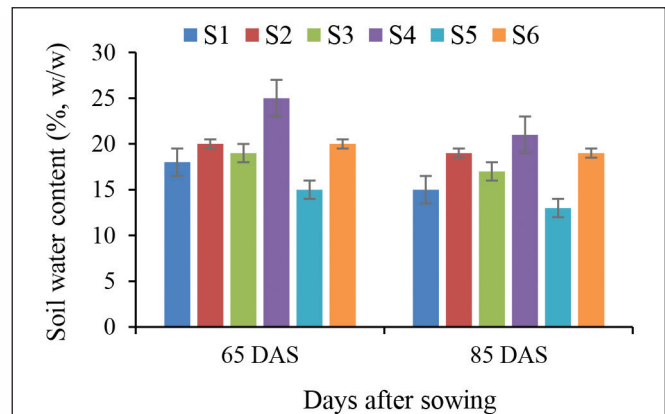


Fig. 4. Soil water content under varying planting systems at different days after sowing of sunflower

and furrow sowing method (-479 kPa) compared to flatbed sowing method (-591 kPa). Plant spacing also significantly affected solute potential and 50 cm × 25 cm spacing had the highest solute potential (-459 kPa). In the study, soil solute potential varied due to planting system at different days after sowing of sunflower and ridge and furrow sowing at 50 cm × 25 cm contained the lowest soil solute potential (-400 kPa at 65 DAS and -380 kPa at 85 DAS). Solute potential was positively correlated to yield and yield contributing characters (Table 3) (Fig. 8D). Water uptake by plants is governed by the total water potential of the root zone soil a

component of which is the solute potential (SP) of the soil solution (Rengasamy, 2006). The SP is proportional to the salt concentration in the soil and inversely related to the soil water content (Chi and La, 2014). Drying of soils elevates salt concentrations in the pore water and decreases soil solute potential (Chen and Jiang, 2010). The higher solute potential with the ridge and furrow method is due to the effect of soil disturbance caused by furrow making which improves water holding capacity in the upper soil layers. Ridge and furrow may also reduce evaporation due to the increased cloddiness at the soil surface and the breakdown of capillary connectedness.

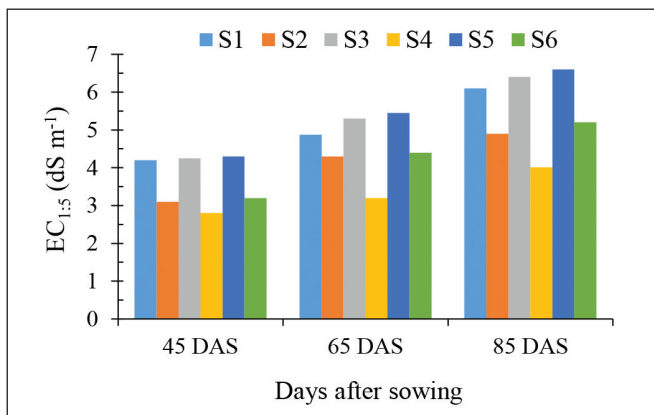


Fig. 5. Soil salinity under varying planting system of sunflower at different days after sowing

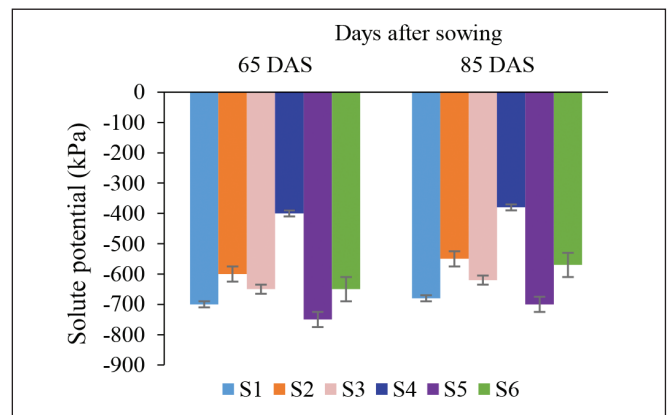


Fig. 6. Soil solute potential under varying planting systems at different days after sowing of sunflower

Crop growth rate

Crop growth rate (CGR) of sunflower from 65 DAS to 85 DAS was higher in ridge and furrow sowing method ($20.9 \text{ g m}^{-2} \text{ day}^{-1}$) than flatbed sowing method ($16.6 \text{ g m}^{-2} \text{ day}^{-1}$). There were statistically significant differences due to different plant spacing. CGR were highest ($23.8 \text{ g m}^{-2} \text{ day}^{-1}$) for 50 cm × 25 cm plant spacing. The S₄ planting system produced the highest CGR at 45-65 DAS and 65-85 DAS which were $18.6 \text{ g m}^{-2} \text{ day}^{-1}$ and $24.4 \text{ g m}^{-2} \text{ day}^{-1}$, respectively (Fig. 7). Again, plant spacing of 50 cm × 25 cm was the optimum plant population to utilize the resource to produce more biomass and higher yield. Leaf area also increased at S₄ planting system. So more photosynthates were produced by ridge and furrow sowing at spacing 50 cm × 25 cm especially at 45 DAS and 65 DAS when CGR and LAI were highest in this treatment combination.

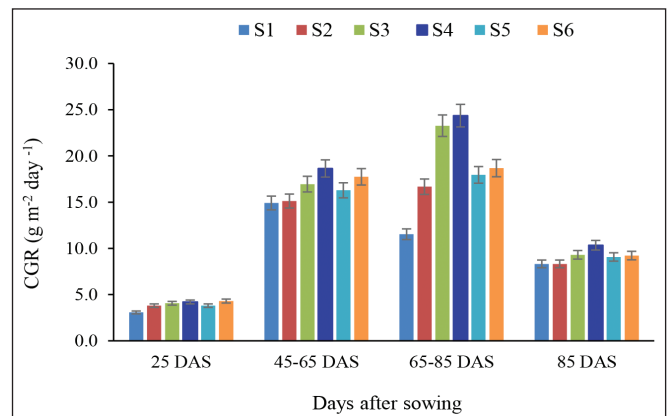


Fig. 7. Crop growth rate of sunflower as influenced by planting systems under saline condition

Yield contributing characters and yield

Analysis of variance showed significant effects of the interaction effect of sowing method and plant spacing. Ridge and furrow sowing at 50 cm × 25 cm spacing produced significantly the highest number of

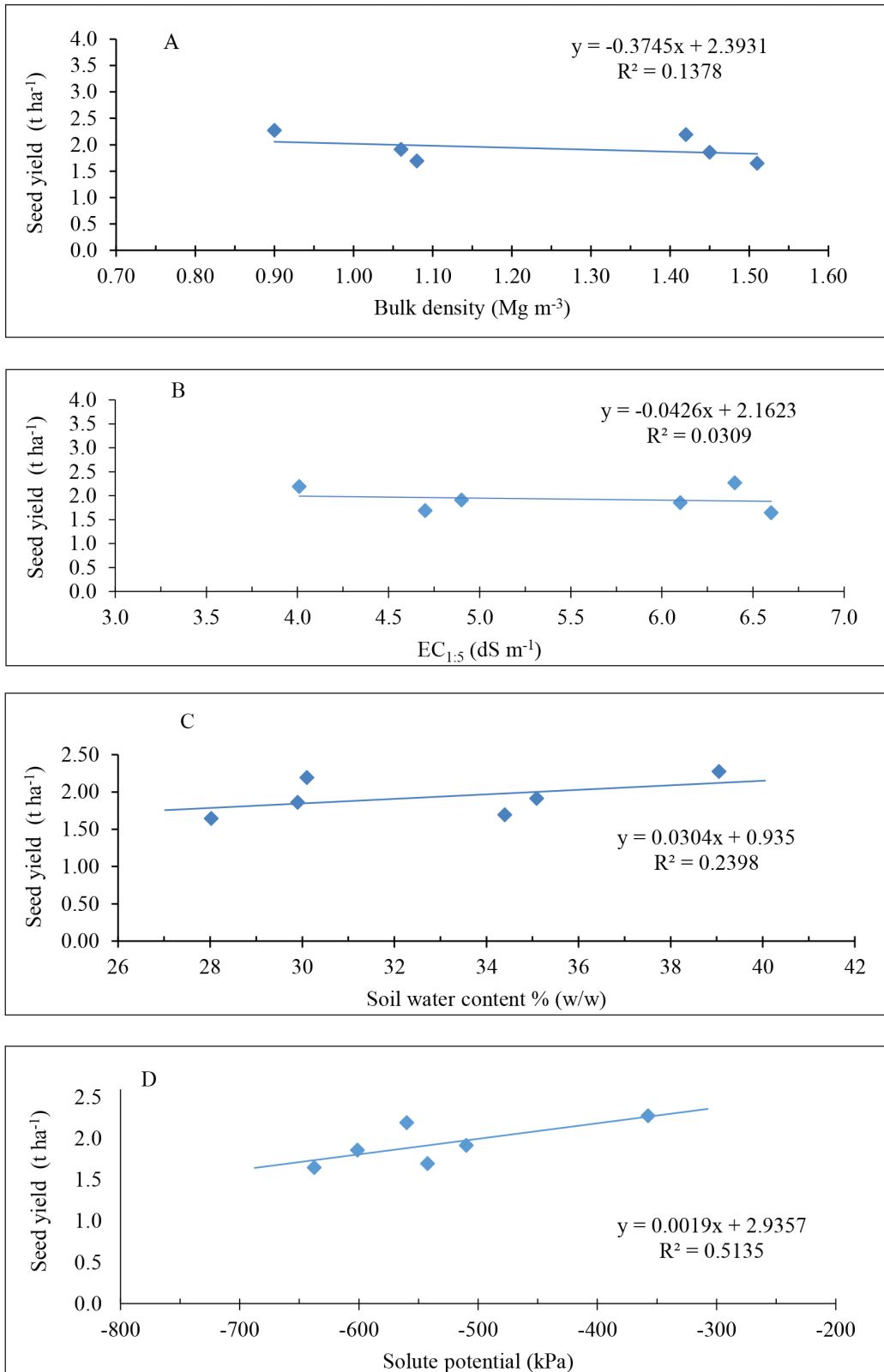


Fig. 8. Regression analysis and prediction of linear trend line of sunflower seed yield with A - bulk density, B - soil salinity, C - soil water content and D - solute potentials

Table 2. Yield contributing characters and yield of sunflower as influenced by the interaction effect of sowing method and plant spacing under saline condition

Particulars	Filled grains head ⁻¹ (no.)	Grain weight head ⁻¹ (g)	Stalk yield (t ha ⁻¹)	Seed yield (t ha ⁻¹)
Planting system (S) (sowing method × plant spacing)				
S ₁ = Flatbed × (40 cm × 25 cm)	572	30.9	3.46	1.86
S ₂ = Ridge and furrow × (40 cm × 25 cm)	565	31.0	3.52	1.92
S ₃ = Flatbed × (50 cm × 25 cm)	600	32.2	3.63	2.19
S ₄ = Ridge and furrow × (50 cm × 25 cm)	650	36.0	4.00	2.27
S ₅ = Flatbed × (60 cm × 25 cm)	527	27.0	2.94	1.65
S ₆ = Ridge and furrow × (60 cm × 25 cm)	517	28.9	3.10	1.69
SEm±	20.0	1.24	0.16	0.10
C.D. (P = 0.05)	54.1	3.37	0.42	0.28
LSD and Significance level	45.5***	4.12***	0.40***	0.21***

*** denotes significant at 0.001 level of probability

Table 3. Correlations matrix between seed yield vs. growth and yield components of sunflower and soil properties

Entry	A	B	C	D	E	F	G	H	I
A Crop growth rate (g m ⁻² day ⁻¹)	1								
B Head diameter (cm)	0.88	1							
C Filled grains head ⁻¹ (no.)	0.96**	0.68	1						
D Grain weight head ⁻¹ (g)	0.96**	0.79*	0.96**	1					
E Stalk yield (t ha ⁻¹)	0.99**	0.61	0.95**	0.95**	1				
F Soil bulk density (Mg m ⁻³)	-0.37	-0.41	-0.35	-0.38	-0.32	1			
G Soil water content (%w/w)	0.44	0.43	0.52	0.38	0.44	-0.99**	1		
H Soil salinity (dS m ⁻¹)	-0.70	-0.66	-0.65	-0.61	-0.62	0.87*	-0.90*	1	
I Solute potential (kPa)	0.61	0.65	0.75	0.66	0.97**	-0.88*	0.94**	-0.93**	1
Seed yield (kg ha ⁻¹)	0.95*	0.96*	0.96**	0.95**	0.99**	-0.87*	0.72*	-0.85*	0.75*

** and * denote significant at 0.01 and 0.05 levels of probability, respectively

filled grains head⁻¹ (650), grain weight head⁻¹ (35.95 g), seed yield (2274 kg ha⁻¹) and stalk yield (4001 kg ha⁻¹). Again, sowing method flatbed and plant spacing 60 cm × 25 cm *i.e.*, S₅ planting system produced the lowest grain weight head⁻¹ (26.99 g), stalk yield (2937.0 kg ha⁻¹) and seed yield (1646 kg ha⁻¹) (Table 2). The significant difference in the interaction of sowing method and plant spacing was mainly due to plant spacing. For the same plant spacing there were no significant differences due

to sowing method (Table 2). It can be concluded that ridge and furrow sowing method following 50 cm × 25 cm plant spacing was the best treatment combination in respect to planting system for the salt affected polder area of Bangladesh.

CONCLUSION

On wet-clay soil in the salt-affected polder area of Bangladesh, the ridge and furrow sowing method

Table 4. Relationship of seed yield vs. growth and yield parameters of sunflower

Sl no	Seed yield (kg ha ⁻¹) vs	Regression constants, coefficients and test statistics				
		Intercept (a)	Regression coefficient (b)	t-value for testing 'b'	R ²	F value for testing R ²
A	Crop growth rate (g m ⁻² day ⁻¹)	1263	35.5	1.71	0.84	2.92
B	Head diameter (cm)	-2089	292	1.74	0.87	3.02
C	Filled grains head ⁻¹ (no.)	-939	5.01	6.63	0.92	43.9
D	Grain weight head ⁻¹ (g)	-324	72.7	6.93	0.92	48.1
E	Stalk yield (t ha ⁻¹)	-31.2	0.57	27.7	0.99	765
F	Soil bulk density (Mg m ⁻³)	2393	-375	-0.80	0.14	0.64
G	Soil water content (% w/w)	935	30.4	1.12	0.24	1.26
H	Soil salinity (dS m ⁻¹)	3064	-919	-1.81	0.03	3.62
I	Solute potential (kPa)	2936	1.88	2.05	0.51	4.22

enhanced water storage in the surface layers of the soil profile and decreased soil salinity. The flatbed sowing method had higher bulk density and lower solute potential in soil surface layers. Plant spacing of 50 cm × 25 cm ensured the optimum plant population of sunflower for the use of resources. Ridge and furrow sowing method was found most effective for reducing salinity effects and achieving maximum yield of sunflower in the salt-affected area. The recommended planting system for sunflower in the Ganges Tidal Floodplain (AEZ 13) can be the ridge and furrow sowing method maintaining 50 cm × 25 cm spacing for obtaining higher yields under saline conditions.

CONFLICTS OF INTEREST

We declare that all authors have participated in (a) conception and design, or analysis and interpretation of the data (b) drafting the article or revising it critically for important intellectual content and (c) approval of the final version. We do not have any conflict of interests in the outcome of this research finding.

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