J. Bangladesh Acad. Sci. 44(2); 145-159: December 2020 DOI: 10.3329/jbas.v44i2.51459

Journal of Bangladesh Academy of Sciences

Journal homepage: http://www.bas.org.bd/publications/jbas.html

Research article

Identifying coastal saline soil management practices to reduce land degradation and increase crop production in Bangladesh

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ARTICLE INFO

Article History

Received: 16 September 2020

Revised: 07 December 2020

Accepted: 15 December 2020

Keywords: Convex bed; Land degradation; Na:K ratio; Plastic mulch; Saline soil

ABSTRACT

A consecutive three year duration field experiment was carried out to identify which of a suitable mulch material and a planting bed or their combinations potentially reduce salt accumulation in soil and increase snake gourd yield in coastal saline soils. There were nine treatment combinations having three kinds of mulch materials: no mulch (control), rice straw mulch and plastic mulch, and three kinds of planting beds: convex bed, flat bed and concave bed. Plastic mulch reduced electrical conductivity of soil by 32% and increased soil temperature by 23% and gravimetric soil moisture content by 25% over control treatment. Plastic mulch had a fruit yield of 30.73, 28.06 and 26.32 t ha-^{1}, which was 72, 237 and 268 % higher than control treatment in 2018, 2019 and 2020, respectively. The convex bed planting had significantly higher fruit yield than flat bed and concave bed planting. Plastic mulching and convex bed planting may therefore be recommended for reducing soil salinity and improving snake gourd yield in coastal saline regions.

Introduction

Severe soil and water salinity are a great concern in the coastal region of Bangladesh, the salt affected area, which has increased by about 27% from 1973 to 2009 (SRDI 2010). Increased salinity significantly reduced crop growth and yield (Haque et al., 2014, Ahmed et al., 2017, Haque et al., 2018). Scientists have paid attention to developing saline soil management practices, and different kinds of tillage systems have so far been developed. Among them, raised bed planting is gaining importance for row crops (Sayre 2007) due to of 25-30% water savings and increased water use efficiencies (Devkota et al., 2013).

Regarding the raised bed furrow irrigation tillage system, irrigation water, when applied to the furrows on every side of the bed, allows salts to leach down from the furrows (Bakker et al., 2010). But the evaporation of water during the drying periods results in salt accumulation on the tops and side slopes beds is center (Richards, 1954). Such salt movement to the center of the bed may damage young plants seeded there (Brady and Well, 2013).

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Permanent skip furrow irrigation reduces the salinity and amount of irrigation water on a raised bed system (Devkota et al., 2015). Micro-sprinkler irrigation is another option that could be successfully used to cultivate plants for the reclamation of coastal saline land (Chu et al., 2015). However, furrow irrigation, flood irrigation, or sprinkler irrigation requires a huge amount of fresh water. Fresh water resources are scarce in coastal saline areas; thus, water-saving irrigation regimes are needed (Sun et al., 2017). Growing high value vine crop in a convex pit and irrigating only in the foot of the crop may dilute the salt concentration in the root zone area, which ultimately may contribute to a higher yield of a crop.

Combining the pit's mulching and shape could be very useful because it changes soil moisture and salinity distribution Mulched drip irrigation considerably decreases soil evaporation (Qi et al., 2018). Mulching technologies have been shown to reduce total evapotranspiration, effectively promote growth, crops' and increase the water use efficiency compared with the check (Li et al., 2018).

Mulching with crop residues in raised beds planting system has shown great potential to reduce soil salinity in salt-affected areas (Devkota, 2011). However, crop residues are not always available in sufficient quantities for mulching due to the high demands for feed and biofuel (Kienzler et al., 2012).

Plastic film mulching along with convex bed planting could be a powerful tool to manage saline soil. This is because plastic film mulching significantly increases top layer soil temperature in an early growth stage, reduces soil evaporation in the early stage, increases transpiration, accelerates plant growth and advances maturity and helps achieve higher yield and water use efficiency (Yang et al., 2018). Plastic film-mulch, along with root zone irrigation, can provide an alternative option to prevent the risk of soil salinization leading to land degradation and enhance crop producti-vity in the arid regions (Tan et al., 2017). In the present investigation, two kinds of mulch materials other than control and three different shapes of planting beds were evaluated to minimize salinity induced land degradation and increase crop yield in coastal seasonal fallow lands.

Materials and Methods

A farmer's field-based experiment was conducted during the rabi season of 2018, 2019 and 2020 at Kalapara upazila of Patuakhali district and Taltali and Amtali upazila of Barguna district, Bangladesh, respectively. The experimental field was medium high land under the AEZ 13, Ganges Tidal Flood Plain Soil. Texturally the Kalapara Upazila soil was loam having 11.6 % sand, 65.0% silt and 23.4% clay. The pH of the initial soil composite was 5.66 and it contained 0.09% total nitrogen (N), 6.4 mg kg-1 available phosphorus (P), 181.9 mg kg-1 available sulfur (S), and 37.84 meq 100 g-1 soil exchangeable sodium (Na) and 0.35 meq 100 g-1 soil exchangeable potassium (K). Electrical conductivity determined in 1:5 soil water suspension ($EC_{1.5}$) was found to be 0.67 dS m-1. The Taltali upazila soil was silty clay loam having 32% clay, 65% silt and only 3% sand. The initial soil had a pH 4.78, electrical conductivity ($EC_{1:5}$), 0.95 dS m-1, 0.075% total N, 4.25 mg kg-1 available P, 141.4 mg kg-1 available S contents. Regarding Amtali upazila, texturally the soil was again silty clay loam having 38% clay, 60% silt and only 2% sand. The initial soil had a pH 4.54,

$EC_{1.5}$0.71 dS m-1, 0.050% total N, 2.83 mg kg-1 available P and 157 mg kg-1 available S contents.

The experiment was laid out in a two factor randomized complete block design. The first factor was the mulching with three levels comprising no mulch, rice straw mulch and plastic mulch; the second factor was three kinds (shapes) of seedling transplanting beds like a convex bed, flatbed, and concave bed. Thus nine treatment combinations were replicated four times. The treatments were randomly distributed to the plots in each block. The test crop was snake gourd and the crop variety was Lalteer hybrid Chichinga-Padma.

The whole land was prepared by ploughing, followed by laddering three times. For planting seedlings a circle area of one-meter diameter was further deep ploughed by a spade to achieve a fine structure of the soil. In the experiment, three kinds/shapes of seedling planting beds were prepared. There was no change in soil surface in the flatbed type and it was parallel to the field soil. The convex bed type was prepared by making the bed at least 5 cm higher than the field soil level. The center of the concave bed was at least 5 cm lower than the field level. The structure of different kinds of seedling planting bed is given in Fig. 1. In plastic mulch system, the seedling transplanting bed (pit) soils were covered with a one square meter size blue color plastic film (polythene sheet). In the rice straw mulch system, the seedling planting bed was covered with rice straw @ 5 t ha^{-1}.

Seedlings were raised in polybag. Fully decomposed cow dung was mixed with soil. The 10 cm long polybag was filled with soil-cow dung mixture. One sprouted seed was sown in each polybag. The seedlings in the polybag were watered whenever necessary. Twenty day old healthy seedlings were used for transplanting. In polythene mulch system the seedlings were transplanted in soil within the 5 cm diameter round-cut portion in the central point of the polythene sheet on 08 January 2018, 05 January 2019 and 01 January 2020. Plant spacing was 2 m × 2 m.

Every plant received equal amount of N, P and K @ 75, 30 and 50 kg ha^{-1}, respectively. The source of N, P and K were urea, triple super phosphate (TSP) and muriate of potash (MoP), respectively.

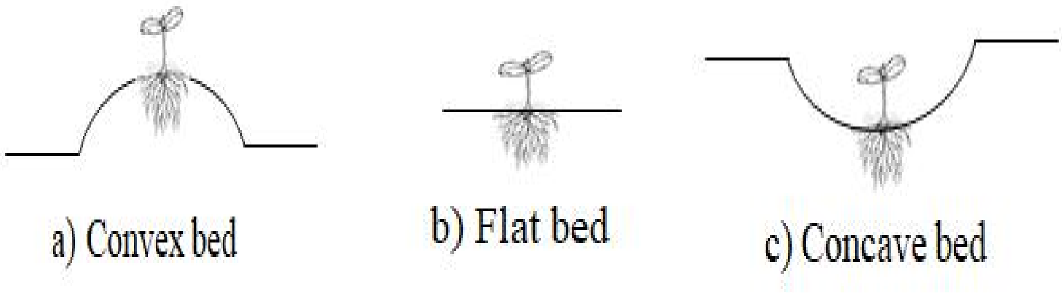

Fig. 1. Structure of different kinds of the seedling planting bed.

In all the experimental plots TSP and MoP were applied during final land preparation. Urea was applied in three equal splits at 10, 25 and 45 days after transplanting. An amount of 1000 mL irrigation water twice in a week was given in the root zone area of each plant.

Data on soil temperature were recorded on 06th March 2018 at 1.00 pm. Soil samples were collected in the same date from the foot of each plant and analyzed for determination of pH in 1:2.5 soil water suspension, electrical conductivity in 1:5 soil water suspension, and chloride and bicarbonate ion contents by volumetric analysis method following standard procedures. The mature fruits were harvested four times with one week interval. The yield data were expressed as fresh weight basis. The mature fruits were chemically analyzed for proline (Bates et al., 1973), total sugar (Dubois et al.. 1956), and sodium and potassium contents (Yoshida et al., 1976). The fruit chemical analysis data were presented on a fresh weight basis. The chemical analysis of plant and soil samples was done in the Department of Soil Science, Patuakhali Science and Technology University, Bangladesh. For shortening the data volume, the growth and yield contributing data, and soil and fruit analysis data are presented only for the 2018 experiment. Data recorded on soil and crop characters were subjected to statistical analysis through the computer-based statistical program STAR (Statistical Tool for Agricultural Research).

Results and Discussion

Effects of mulching and planting beds on soil physical and chemical properties

Electrical conductivity (EC) is the most crucial determinant to measure the salinity of soil and the status of salinity induced land degradation. Periodic soil samples were collected from a central point of the study experiment to see the temporal variability of soil salinity and analyzed for electrical conductivity in 1:5 soil water suspensions and expressed as $EC_{1:5}$. The soil's electrical conductivity was found to vary over a big range from 0.67 to 5.4 dS m-1 over the study period (Fig. 2). The $EC_{1:5}$ value was found to be only 0.67 dS m-1 on 1st December, and progressively increased with time. From February to April, the soil was strongly affected by salinity, which then further declined with the onset of monsoon rain. Due to the very high level of soil salinity in February to April, most farmers keep their land fallow in rabi season in coastal regions of Bangladesh.

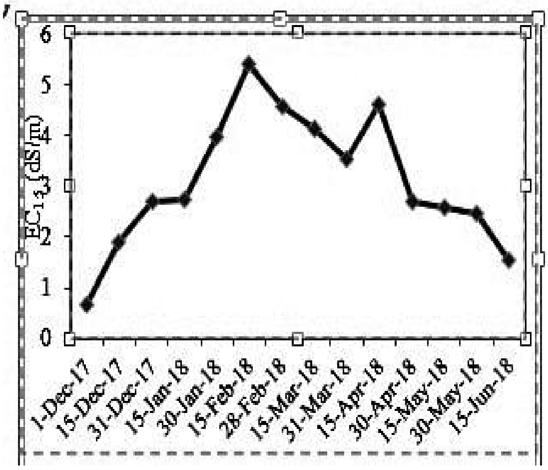

Fig. 2. Temporal variability of soil electrical conductivity values.

In the investigation, different kinds of mulch materials and different shapes of planting beds were used to reduce electrical conductivity ($EC_{1:5}$) of soil, and their effect is presented in Figure 3. Plastic mulch had a significant impact on reducing the salinity of the soil. Over the planting beds, plastic mulch consistently had the significantly lowest $EC_{1:5}$ value, which was 32%

lower than that in the control treatment. It creates a comfortable soil condition, which ultimately helps better crop growth and yield. In the experiment, the $EC_{1:5}$ of soil was very strongly and negatively correlated with fruit yield of snake gourd (r=-0.917), which indicates that the increase in salinity reduces the crop yield (Table 5). The negative correlation of EC and yield was also reported by Zheng et al. (2009) and identified as the key limiting factor for cotton growth under the drip irrigation system. Haque et al. (2018) reported that the use of plastic mulch significantly reduces the soil's electrical conductivity. Considering the single effect of planting beds, the significantly lowest

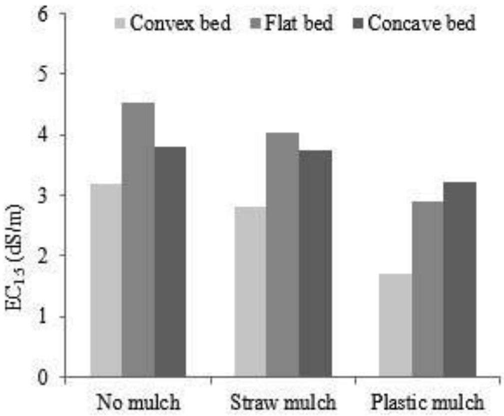

Fig. 3. Soil electrical conductivity as influenced by mulching and planting beds.

Sig. level: Mulching***, Planting bed-*** and Interaction-NS; %CV-10.6; LSD- 0.35.

***Significant at 0.1% level.

$EC_{1:5}$ value was found in convex bed planting (2.57 dS m-1). The flat bed (3.83 dS m-1) and concave bed (3.59 dS m-1) had statistically similar $EC_{1:5}$ value. Generally, the EC value presented in the graph seems to be non-saline as most of the values are lower than 4. Actually, in the experiment, the EC value was determined in 1:5 soil water suspension. To get an EC value equivalent to EC in saturation paste extract, the EC value found in 1:5 soil water suspension will be multiplied by 5. According to the Soil Resource Development Institute of Bangladesh, these values will be then fitted in an equation. Finally, the EC in saturation paste extract will be more than 5 times higher than EC in 1:5 soil water suspensions. In the present experiment, the EC value of 1:5 soil water suspensions is directly presented in the figures; therefore, the values appeared relatively low.

Soil temperature was significantly influenced by mulch treatments but was not significant in bed systems, and interaction of mulching and bed systems (Table 1). With plastic mulch, the soil temperature was highest (40.2 ºC), whereas, with no mulch treatment, it was 32.7 ºC, which was 23% higher than that in the control treatment. Straw mulch treatment, led to a soil temperature (30.9 ºC) lower than in the control treatment. Soil temperature is an important factor for growing crops in the winter season. Plastic mulch is an effective strategy for promoting crop emergence and rapid growth of crops because it can modify the soil microclimate by increasing the soil temperature (Dong et al., 2018).

Except for soil temperature, all the soil parameters, including soil moisture content, pH, chloride and bicarbonate ion content, were significantly influenced by both the single effect of mulches and planting beds (Table 1). The gravimetric soil moisture content was highest (19.8%) in plastic mulch treatment; the straw mulch had the second highest (16.7%), and no mulch had the lowest soil moisture content (15.8%). Plastic mulch helps maintain higher moisture content even for a longer time

Table 1. Single and interaction effect of mulching and planting bed on soil physical and chemical parameters (presented only for the year 2018).

Treatments	Convex bed	Flat bed	Concave bed	Mulch effect
		Soil temperature (ºC)		
No mulch	32.8	33.0	32.3	32.7 b
Straw mulch	31.3	30.5	31.0	30.9 c
Plastic mulch	41.8	39.3	39.5	40.2 a
Bed effect	35.3	34.3	34.3	
Significance level: Mulching-***, Planting bed-NS and Interaction-NS; %CV- 3.63				
		Gravimetric soil moisture content (%)		
No mulch	15.4	18.4	13.5	15.8 b
Straw mulch	16.1	17.9	16.1	16.7 b
Plastic mulch	21.7	19.9	17.9	19.8 a
Bed effect	17.7 A	18.7 A	15.8 B	
Significance level: Mulching-***, Planting bed-** and Interaction-NS; %CV- 8.56				
		Soil pH		
No mulch	5.30	5.25	5.03	5.19 a
Straw mulch	4.80	4.82	4.82	4.81 b
Plastic mulch	5.51	5.35	4.96	5.27 a
Bed effect	5.20 A	5.14 A	4.94 B	
Significance level: Mulching-***, Planting bed-* and Interaction- NS; %CV- 3.51				
		Soil chloride ion content (%)		
No mulch	0.17 aB	0.18 aB	0.25 aA	0.20 a
Straw mulch	0.11 bA	0.09 bA	0.10 bA	0.10 b
Plastic mulch	0.04 cA	0.05 cA	0.03 cA	0.04 c
Bed effect	0.11 B	0.11 B	0.13 A	
Significance level: Mulching-***, Planting bed-** and Interaction-***, %CV- 12.68				
		Soil bicarbonate ion content (%)		
No mulch	1.40	1.50	2.15	1.68 a
Straw mulch	1.35	1.83	1.93	1.70 a
Plastic mulch	0.85	1.08	1.73	1.22 b
Bed effect	1.20 B	1.47 B	1.93 A	
Significance level: Mulching-**, Planting bed-*** and Interaction-NS; %CV- 25.78				

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*Significant at 5% level, **Significant at 1% level, *** Significant at 0.1% level.

by reducing evaporation loss of water from the soil. Thus plants get the opportunity to take up more water from the soil. Li et al. (2018) tested 7 mulching materials to grow maize crop and reported that all the mulches saved water and accelerated maize growth in the middle and later stages; the highest performance was with plastic mulches. Plastic mulch increases the amount of soil-available water by restricting evaporation and elevating deep water through capillary and vapor transfer to the layer usable for roots under arid and semi-arid conditions (Qin et al., 2014). Among the planting beds, flat beds planting had the highest moisture content (18.7%), which was statistically similar to convex bed planting (17.7%).

The highest pH value of 5.27 was observed in plastic mulch treatment. Convex bed planting also had a higher performance (5.20), although it was statistically similar to flat bed planting (Table 1). For growing crops, around neutral pH is the best. The field of soil under study was strongly acidic. Plastic mulch helps to maintain a relatively higher pH value. A strongly acidic condition favors the availability of several toxic elements, which hampers crop growth.

In the experiment, the chloride ion content was highest in no mulch treatment (0.20%) and lowest in plastic mulch treatment (0.04%). Plastic mulching reduced chloride ion concentration by 80% compared to no mulch condition, which evidenced the soil's safe condition in relation to chloride ion concentration under plastic mulch condition. In planting beds, the highest chloride ion concentration was found in concave beds (0.13%), but convex and flat beds had slightly lower chloride ion concentration (0.11%).

Soil bicarbonate ion concentration was higher than the chloride ion concentration (Table 1). The highest bicarbonate ion concentration (1.70%) was found in the case of straw much treatment. This was found to be statistically similar with no mulch treatment (1.68%). The plastic mulch had only 1.22% bicarbonate ion concentration. The plastic mulch reduced bicarbonate ion concentration by 27% compared to the control treatment.

There was a significant negative correlation of HCO_3^- content of soil (r= -0.842) with fruit yield of snake gourd (Table 5). Like the chloride ion, bicarbonate ion concentration was higher in concave bed planting (1.93%). The convex bed had the lowest bicarbonate ion content, which was statistically similar to that of the flat bed planting.

Effects of mulching and planting beds on fruit yield of snake gourd

Fruit yield was significantly influenced by mulch and types of the planting bed, and their interactions in 2018, 2019, and 2020. Figure 4 shows that plastic mulch treatment had a consistently outstanding performance in three years across the planting beds compared to rice straw mulch and no mulch treatment. Rice straw mulch had better performance than no mulch treatment. Based on the single effect, plastic mulch had fruit yields of 30.73, 28.06, and 26.32 t ha^{-1}, which was 72, 237 and 268 % higher than no mulch control treatment in 2018, 2019 and 2020, respectively. The increased yield in plastic mulch treatment increased vegetative and reproductive growth in this treatment. Li et al. (2018) also found the highest yield and water use efficiency in plastic mulch treatment than the other seven mulch materials tested. Comparatively lower yield in no mulch and straw mulch treatment was probably due to salinity in the soil.

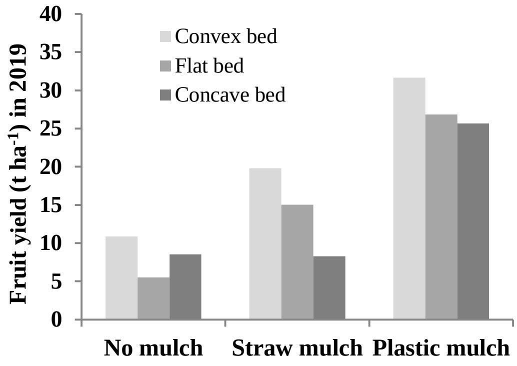

Fig. 4a. Kalapara, Patuakhali

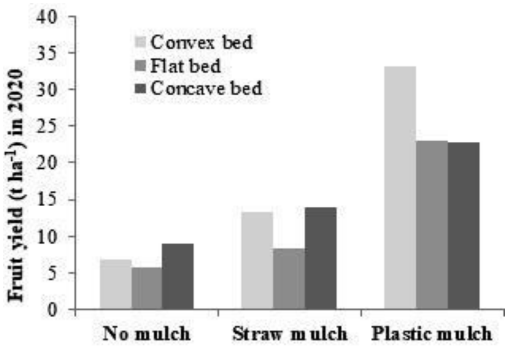

Fig. 4b. Taltali, Barguna

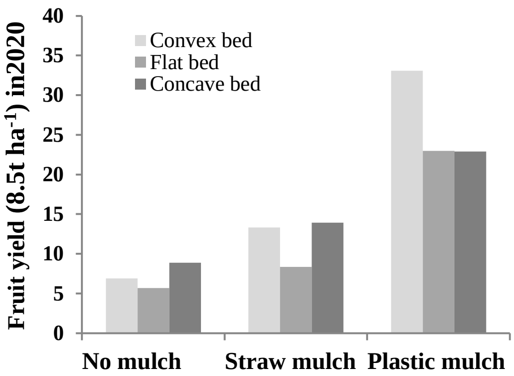

Fig. 4c. Amtali, Barguna

Fig. 4. Fruit yield (t ha^{-1}) of snake gourd in 2018, 2019 and 2020 as influenced by mulching and planting beds.

Significance level both in 2018, 2019 and 2020: Mulching-***, Planting bed-*** and Interaction-***; %CV- 9.41 in 2018, 11.94 in 2019 and 11.58 in 2020; LSD value- 3.19 in 2018, 2.95 in 2019 and 2.99 in 2020. *** = Significant at 0.1% level.

Among the planting beds, the convex bed had the best performance over the flat bed and concave bed. The result was consistent in 2018, 2019, and 2020. Considering single effect, the convex bed planting had fruit yield of 31.32, 20.78, and 17.76 t ha^{-1} in 2018, 2019 and 2020, respectively; and these yields were 54% and 72% higher in 2018, 32% and 47% higher in 2019, and 44% and 17% higher in 2020 over flat bed and concave bed, respectively. The flat bed and concave bed could not provide a favorable soil environment for optimum plant growth. In supporting similar findings, Li et al. (2017) described that ridge planting is more sustainable and effective than flat planting for reclamation of saline soils in coastal regions.

A combination of plastic mulch and the convex bed gave the highest fruit yield of 36.65, 31.67, and 33.08 t ha^{-1} in 2018, 2019 and 2020, respectively (Fig. 4). The flat bed performance and the concave bed had no consistent pattern in no mulch and rice straw mulch treatment; however, flat bed had consistently better performance than the concave bed in plastic mulch treatment.

The economic viability of using different mulch materials under different planting bed systems was determined through the calculation of the marginal benefit-cost ratio (MBCR) of the mulch treatments. The economic analysis was done using three year mean fruit yield data. A summary of the results is shown in Table 2. The marginal benefit-cost ratio (MBCR) is the ratio of marginal or added benefits and added costs. The following formula was used to compare different mulch treatments with no mulch control treatment.

$$MBCR(over\ no\ mulch\ control) = \frac{Gross\ return\ in\ mulch\ treatments - Gross\ return\ in\ no\ mulch\ treatment}{Variable\ cost\ in\ mulch\ treatments - Variable\ cost\ in\ no\ mulch\ treatment}$$

$$MBCR\ (over\ no\ mulch\ control) = \frac{Added\ benefit\ (over\ control)}{Added\ cost\ (overcontrol)}$$

Gross return = Yield × price

Table 2. Economic profitability of using different mulch materials under different bed systems for growing snake gourd in coastal saline soils of Bangladesh.

Treatments	Gross return (Tk)	Added benefit (Tk)	Added cost (Tk)	MBCR
T_1: No mulch×Convex bed	440244	-	-	-
T_2: Straw mulch×Convex bed	641544	201300	20000	10
T_3: Plastic mulch×Convex bed	1014006	573762	60000	10
T_4: No mulch×Flat bed	261563	-	-	-
T_5: Straw mulch×Flat bed	349331	87768	20000	4
T_6: Plastic mulch×Flat bed	843650	582087	60000	10
T_7: No mulch×Concave bed	352469	-	-	-
T_8: Straw mulch×Concave bed	380469	28000	20000	1
T_9: Plastic mulch× Concave bed	695750	343281	60000	6

Values were generated through calculation; therefore, statistical analysis did not performed.
Price: Snake gourd- Tk 30000 t^{-1}, Rice straw- Tk 20000 ha^{-1}, Plastic mulch- Tk 60000 ha^{-1}.

Under the convex bed planting system, the straw mulch and plastic mulch both had MBCR of 10, but in the flat bed system, these two mulch materials gave MBCR of 4 and 10, respectively. If we consider the concave bed planting system, the rice straw mulch and plastic mulch gave MBCR of 1 and 6, respectively. The results indicate that under flat bed and concave bed planting systems, plastic mulch is highly profitable. Under the convex bed planting system, mulch material was also highly economical, but there was no difference between straw mulch and plastic mulch.

Effects of mulching and planting beds on growth and yield contributing characters of snake gourd

Primary stem length and the number of branches per plant were significantly influenced by mulch materials, types of planting beds, and interactions between them. Considering single effect plastic mulch had the most extended stem of 364.8 cm (Table 3), rice straw mulch had the second rank (207.2 cm). Among the planting beds, convex bed had the most extended stem (245.3 cm), followed by flat bed (207.8 cm) and a concave bed (173.6 cm). Considering the interaction effect, plastic mulch with convex bed planting had the

Table 3. Single and interaction effect of mulching and planting bed on growth and yield contributing characters of snake gourd (presented only for the year 2018).

Treatments	Convex bed	Flat bed	Concave bed	Mulch mean
		Stem length (cm)		
No mulch	216.0 bA	133.8 cB	114.3 cB	**154.7 c**
Straw mulch	232.3 bA	221.3 bA	168.0 bB	**207.2 b**
Plastic mulch	287.5 aA	268.5 aA	238.5 aB	**264.8 a**
Bed mean	**245.3 A**	**207.8 B**	**173.6 C**	
Significance level: Mulching-***, Planting bed-*** and Interaction-***;%CV- 8.47				
		Branches per plant (no.)		
No mulch	6.0 cA	4.0 cB	3.5 cB	**4.5 c**
Straw mulch	9.3 bA	6.3 bA	5.5 bA	**7.0 b**
Plastic mulch	18.3 aA	10.3 aB	9.0 aB	**12.5 a**
Bed mean	**11.2 A**	**6.8 B**	**6.0 B**	
Significance level: Mulching-***, Planting bed-*** and Interaction-***; %CV- 15.47				
		Fruit per plant (no.)		
No mulch	7.8	2.0	4.0	**4.6 c**
Straw mulch	9.3	5.3	6.0	**6.9 b**
Plastic mulch	17.3	12.8	8.3	**12.8 a**
Bed mean	**11.4 A**	**6.7 B**	**6.1 B**	
Significance level: Mulching-***, Planting bed-* and Interaction-NS; %CV- 54.08				

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*Significant at 5% level, ***Significant at 0.1% level.

highest performance (287.5 cm). Similar to the stem length, plant branching was extremely influenced by both mulch and bed treatments.

Plastic mulch had 12.5 branches, which were more than double compared to straw mulch (7.0 branches) and no mulch treatments (4.5 branches). The convex bed treatment had 11.2 branches, flat bed had 6.8 branches and the concave bed had only 6.0 branches per plant. The combined effect of plastic mulch and convex bed planting had the highest of 18.3 branches per plant (Table 3). Based on the single effect, plastic mulch had 12.8 fruit per plant (Table 3). The straw mulch and no mulch produced 6.9 and 4.6 fruits per plant, respectively. The bed effect was also very distinct, having significantly the highest of 11.4 fruits per plant in the convex bed. There was a significant positive correlation of fruit yield with all the growth and yield contributing parameters, including stem length (r= 0.827), number of branches plant^{-1} (r=0.826) and number of fruit plant^{-1} (r=0.936) of snake gourd (Table 5). Haque et al. (2018) used four different kinds of mulch materials for growing maize. They found that all the growth and yield contributing parameters were highly influenced by plastic mulch treatment, which is in good agreement with the present study results.

Effects of mulching and planting beds on fruit biochemical properties of snake gourd

Proline, a vital amino acid used for osmotic adjustment, makes plants stress-tolerant, especially in saline conditions (Dar et al., 2016). During salt stress, plants accumulate a large amount of proline in the cell sap. Thus the higher accumulation of proline is indicative of growing plants in extreme saline conditions. In the experiments, plastic mulch resulted in the lowest proline content (42.8 mg 100 g-1 fruit) followed by straw mulch (61.8 mg 100 g-1 fruit) and no mulch (87.9 mg 100 g-1 fruit), respectively (Table 4). Similarly, in convex bed planting, proline content was the lowest (28.5 mg 100 g-1 fruit). In flat bed planting proline content in the fruits was the highest (75.5 mg 100 g-1 fruit). Looking at the interaction effect, the plastic mulch along with convex bed planting, resulted in the lowest proline content (28.5 mg 100 g-1 fruit). In the experiments, plastic mulch resulted in 51% lower proline content in fruit compared to no mulch control treatment. Furthermore, there was a significant negative correlation of proline content with fruit yield of snake gourd (r=0.829; Table 5). The lowest proline content achieved using plastic mulch treatment indicates that these plants were not affected or less affected by salinity in the experiments. Similarly lowest proline content in convex bed planting indicates its comfortable soil environment.

Total sugar content in the fruits was significantly influenced by both mulching and planting beds. The use of plastic mulch resulted in a total sugar content of 2.264 g 100 g-1 fruit, which was 37% higher than that obtain with no mulch treatment (Table 4). The results indicate that without mulch treatment, favorable soil health could not be maintained. Similarly, convex bed planting yielded 2.588 g 100 g-1 fruit total sugar content, which was 74% and 65% higher than the concave bed and flat bed, respectively. This further indicates that the convex bed was able to maintain good soil health for crop growth. In an interaction effect, the plastic mulch vs convex bed yielded the highest sugar content. Total sugar content was significantly correlated with fruit yield of snake gourd (r= 0.707; Table 5).

Table 4. Single and interaction effect of mulching and planting bed on fruit biochemical parameters of snake gourd (presented only for the year 2018).

Treatments	Convex bed	Flat bed	Concave bed	Mulch effect
		Fruit proline content (mg $100g^{-1}$ fruit)		
No mulch	63.4 aC	106.0 aA	94.5 aB	**87.9 a**
Straw mulch	56.6 bB	81.3 bA	47.7 cC	**61.8 b**
Plastic mulch	28.5 cC	39.1 cA	60.9 bB	**42.8 c**
Bed effect	**49.5 C**	**75.5 A**	**67.7 B**	
Significance level: Mulching-***, Planting bed-*** and Interaction-***; %CV- 4.87				
		Fruit total sugar content (g $100g^{-1}$ fruit)		
No mulch	1.451 cA	1.435 cA	1.380 bA	**1.422 c**
Straw mulch	2.766 bA	1.578 bB	1.542 aB	**1.962 b**
Plastic mulch	3.545 aA	1.702 aB	1.544 aC	**2.264 a**
Bed effect	**2.588 A**	**1.572 B**	**1.489 B**	
Significance level: Mulching-***, Planting bed-*** and Interaction-***;%CV- 2.89				
		Fruit sodium content (%)		
No mulch	0.294 aC	1.176 aB	1.650 aA	**1.040 a**
Straw mulch	0.221 aC	0.956 bB	1.365 bA	**0.847 b**
Plastic mulch	0.294 aC	1.103 abA	0.515 cB	**0.637 c**
Bed effect	**0.270 B**	**1.078 A**	**1.176 A**	
Significance level: Mulching-***, Planting bed-*** and Interaction-***; %CV- 11.43				
		Fruit potassium content (%)		
No mulch	0.150	0.150	0.138	**0.146 b**
Straw mulch	0.163	0.155	0.168	**0.162 a**
Plastic mulch	0.163	0.154	0.183	**0.166 a**
Bed effect	**0.158**	**0.153**	**0.163**	
Significance level: Mulching-*, Planting bed-NS and Interaction-NS; %CV- 9.00				
		Fruit sodium:potassium ratio		
No mulch	1.960 aC	7.848 aB	12.001 aA	**7.270 a**
Straw mulch	1.365 aC	6.170 bB	8.278 bA	**5.271 b**
Plastic mulch	1.809 aB	7.179 abA	2.870 cB	**3.953 c**
Bed effect	**1.711 B**	**7.065 A**	**7.716 A**	
Significance level: Mulching-***, Planting bed-*** and Interaction-***; % CV- 14.87				

Similar small letter in a column and capital letter in a row is not statistically different
*Significant at 5% level, *** Significant at 0.1% level.

Sodium content in fruit is a good indication of Na content in the soil. The higher is the Na content in soil higher is the salinity of the soil. The sodium content of snake gourd fruit was highest when no mulches were used (1.04%). The straw mulch treatment yielded fruits with lower Na-content (0.962%), and plastic mulch yielded fruits with the lowest Na-content (0.637%) (Table 4). To determine the bed effect, the convex bed treatment resulted in the lowest Na content (0.270%) and it progressively increased in flat bed (1.078%) and the concave bed (1.176%). Among the interaction effects, no mulch with a concave bed resulted in the highest Na content (1.650%). The experiments further showed that plastic mulch reduced fruit Na content by 39% compared to no mulch treatment. It indicates that Na content was lower in plastic mulch treatment soil, which results in lower uptake of Na from the soil. A similar result was also found in planting systems where a flat bed and concave bed yielded 299% and 335% higher Na content over convex bed planting. The lower Na content was one of the primary reasons for higher yield in the convex bed planting system.

The scenario of K content was different from that with Na content. The highest K content was found in plastic mulch treatment (0.166%), which was statistically similar to straw mulch treatment (Table 4). This sodium/potassium ratio is an essential determinant for the salt tolerance of crops. The higher the ratio is, the higher is the susceptibility of crops, and the lower value of the ratio indicates a comfortable soil environment. In the study, the soil had the lowest Na:K ratio (3.953) in plastic mulch treatment. The ratio was 5.271 in the case of straw mulch treatment and 7.270 in no mulch treatment. Similarly, the Na:K ratio was only 1.711 in the case of convex bed, and 7.065 in flat bed and 7.716 in concave bed. Without mulch treatment in a concave bed, the Na:K ratio had the highest value (12.00). A higher sodium/potassium ratio is rather more detrimental than the sole Na content of the soil. Higher Na:K ratio makes plant Na toxic and deficient in K (Almeida et al., 2017). In the experiment flat bed, the concave bed had several fold higher Na:K ratio than convex bed planting. Similarly, soil treated with plastic mulch had a Na:K ratio half of the value for no mulch condition. Thus, in plastic mulch and convex bed treatment, plants enjoy the least saline environment, which might be safe for growing snake gourd.

Table 5. Correlation between different soil and plant parameters with fruit yield of snake gourd.

Parameters	Fruit yield
Stem length	0.827**
Branches plant^{-1}	0.826**
Fruit plant^{-1}	0.936***
Proline content of fruit	-0.829**
Sugar content of fruit	0.707*
Electrical conductivity of soil	-0.917***
HCO_3^- content of soil	-0.842**

*=Significant at 5% level, **=Significant at 1% level, ***=Significant at 0.1% level.

Conclusion

Plastic mulch could be very much promising to manage saline soil because it improves crop yield by reducing soil salinity and increasing soil temperature and moisture content. The convex bed planting along with plant foot zone irrigation could also be a potential tool to increase vine crop yield in saline soils. A combination of plastic mulch and convex bed planting could significantly benefit the farmers of the coastal region.

Acknowledgements

This work was supported by the Bangladesh Academy of Sciences (BAS) through BAS-USDA collaborative research endeavor program under the project entitled "Development of saline soil management technologies for the introduction of high-value crops in the coastal fallow lands of Bangladesh (Project ID: BAS-USDA PALS CR-37).

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