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Microclimatic Alteration and Productivity of Mustard Crop as Induced by Indigenous Mulches

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ABSTRACT

An experiment was carried out in the Crop Botany Field Laboratory, Bangladesh Agricultural University, Mymensingh to find out the effect of indigenous mulches viz. rice straw, ash and sawdust on the microclimate, growth and yield of mustard crop cv. Shafol (*Brassica campestris* var. Yellow Sarson) during the winter season extended from November 2008 to February 2009. As compared to ash mulch and control (i.e. no mulch), the straw and sawdust mulches decreased the temperature but increased the moisture content of the soil. The mustard crop grown with sawdust mulch showed better performances for most of the parameters like shoot height, number of primary branches/plant, leaf area index, dry matter accumulation and yield components and yield. The sawdust mulched crop produced (1.54 t ha^{-1}) about 35 and 20% higher seed yield than the crops grown with straw mulch (1.00 t ha^{-1}) or no mulch (1.24 t ha^{-1}). A heavy mulch cover like rice straw is unsuitable for mustard cultivation because the seedlings are so soft and succulent that many plantlets could not emerge out successfully by penetrating up through the straw mulch cover thus fail to establish as good crop stands. In contrast, the loose or powdery mulch like sawdust is proved to be beneficial for establishing good crop stands with higher production of mustard.

Key words: *Brassica campestris*, dry matter, leaf area index, microclimate, mulch, yield

INTRODUCTION

Crop production in Bangladesh is predominantly based on rainfall and its annual distribution. About ninety percent rainfall is occurred during monsoon season started from June to September. In the remaining period drought of different degrees occurs in almost all areas of the country that would seriously hampers the crop production if irrigation facility is not available there on. About 43% of total agricultural land in Bangladesh has got irrigation facilities and remaining either under rainfed cultivation during winter season or fallow up to the end of the dry period. Application of mulches could supplement the irrigation demands in a greater extent as it has been proved to conserve or retain the soil moisture successfully (Midmore *et al*., 1986; Sui *et al*., 1992; Gill *et al*., 1996; Ramakrishna *et al*., 2006).

Mustard is one of the major oil yielding crops that occupies about 80% of the total oilseed cropped area which contribute nearly 71% of the total oil requirements in Bangladesh. Generally mustard cultivation is dependent on the residual soil moisture from previous monsoon. Such residual moisture quickly dries up with mustard growth that caused limitation of soil moisture during reproductive stage which is one of the major causes for the poor yield of mustard in Bangladesh. The use of mulching materials not only conserves soil moisture but may also reduce soil temperature, minimizes evaporation loss and enhances root growth (Singh *et al.*, 2011; Faget *et al.*, 2012). The effect of mulches on soil temperature and moisture regime and root growth as well as yield depend on the climate of the locality, mode of mulch application and quality and quantity of the mulch materials used (Lal, 1978; Sui *et al.*, 1992; Anikwe *et al.*, 2007). Mulching also improves soil physical condition by altering the mechanical impedance to root penetration, hydraulic conductivity and water holding capacity (Maurya and Lal, 1981; Glab and Kulig, 2008). Since most of the land of Bangladesh remains fallow in winter season due to the shortage of water, the use of cheap and locally available indigenous mulches may provide a better avenue for mustard cultivation. Moreover, residual effect of indigenous mulches may add organic matter and some plant nutrients into the soil (Cadavid *et al.*, 1998; Leblanc *et al.*, 2006; Youkhana and Idol, 2009). The effect of different type of mulch materials especially indigenous mulches has been proved for altering the microclimate (Stigter, 1984; Sharratt and Glenn, 1988; Awal and Ikeda, 2002) and thereby growth and yield of many crop stands (Decoteau *et al.*, 1988; Awal and Ikeda, 2003a, b; Anikwe *et al.*, 2007; Kumar and Dey, 2011; Murungu *et al.*, 2011). However, the effect of mulching on the growth and yield of mustard crop is yet to be reported else. Therefore, the present investigation was undertaken:

- To observe the effect of different indigenous mulches viz. rice straw, ash and sawdust along with a control treatment (i.e. no mulch) on microclimatic parameters like soil temperature and soil moisture
- To find out the effect of said mulches on the growth and yield of mustard cv. Shafol (*Brassica campestris* L. var. Yellow Sarson) in relation to altered microclimate
- To identify the best indigenous mulch for the better production of mustard crop under the agro-climatic conditions of Bangladesh

MATERIALS AND METHODS

The experiment was conducted in the Crop Botany Field Laboratory of Bangladesh Agricultural University during the dry winter season extended from November 2008 to February 2009. Geographically the site (24°75' N latitude and 90°50' E longitude at an elevation of 18 m above the sea level) belong to the sub-tropical climatic. The topography of the experimental field was medium high land belonging to the Sonatala Soil Series of gray flood plain soil type under the Agro Ecological Zone-9, named Old Bramhaputra Flood Plain. The soil was silty loam with imperfectly to poorly drained permeable. The land was prepared by deep ploughing with a power tiller. The weeds and stubbles were removed from the plots as far as possible. Recommended doses of manures and fertilizers were mixed to the soil. The unit plot size was 3×2 m.

The experiment comprised four mulching treatments viz. no mulch (control), rice straw, ash and sawdust mulches followed by a Randomized Complete Block Design with four replicates. Seeds of mustard cultivar-'Shafol' (*Brassica campestris* L. var. Yellow Sarson) were sown by hand on 12 November 2008 maintaining 25 cm space between lines and 10 cm between plant to plant within a line. Soon after seed sowing the plots were covered by the selected mulches @ 1 kg m^{-2} as per experimental design. The mulch materials were spread out uniformly throughout the plots. Different intercultural operations especially weeding and control of insect pests and diseases were done as and where needed.

Microclimatic parameters viz. soil temperature and moisture were measured on 29 and 59 days after sowing (DAS). Daytime soil temperatures were measured at hourly interval starting from sunrise to around sunset. Soil temperature data were collected at 5 and 10 cm soil depths with graduated-transparent soil thermometers covered by metallic case. Soil moisture contents at 5-15 cm depth were measured gravimetrically with the following formula:

$$\text{Soil moisture content (\%)} = \frac{\text{Intial weight} - \text{Oven dry weight}}{\text{Initial weight}} \times 100$$

Ten plants from each plot were randomly harvested to record the data on seasonal growth traits like shoot height (measured with a graduated scale placed vertically from ground level to the top of the shoot), number of primary branches/plant (the branches on the main stem of the plant), leaf area, dry matter accumulation at 15 days interval starting from 30 days after sowing (DAS) continued till maturity of crop (90 DAS i.e. 9 Feb 2009). The leaf areas were measured by an Electronic Area Meter (LICOR, LI-3000, USA). The Leaf Area Index (LAI) was calculated as leaf area/ground area basis. To record the data on dry weight the plant samples were dried in an oven at 80±2°C until constant weight. The crop was finally harvested at physiological maturity to record the data on yield components and yield viz. number of siliqua/plant, number of seed/siliqua, number of seed/plant, 1000-seed wt. (g), seed wt. (g)/plant, seed yield, total dry matter yield (i.e. biological yield) and harvest index.

Statistical analysis: All data were statistically analyzed and the mean differences were evaluated by Least Significant Difference (LSD) or Duncan's New Multiple Range Test (Gomez and Gomez, 1984).

RESULTS

Soil temperature: The daytime soil temperatures on 29 DAS were found minimum soon after sunrise and it gradually rose up with the progress of the day followed by gradual decrease after attaining the peak value at about 14-15 h (Fig. 1). Air temperature always maintained higher values than the soil temperature of the respective hours for the entire daytime course except early morning (up to 8 or 9 h). At 5 cm depth, the soil under ash mulch showed highest soil temperature followed by bare soil. However, the result was opposite for 10 cm depth. In contrast, the lowest soil temperature was noticed under straw followed by sawdust for both layers of soil (i.e. 5 and 10 cm depths). The daytime course of soil temperature on 59 DAS for all the treatments was found as that found at 29 DAS but the inter treatment difference was less distinct (data not shown) might be due to the mutual shading offered from developing crop canopy.

Soil moisture: The mulch covers exerted significant role on the retention of soil moisture. The soil subjected to straw cover conserved greater amount of soil water followed by sawdust and the bare soil conserved the minimum (Fig. 2). The soil subjected to ash cover ranked intermediate. Therefore, the magnitude of retention of soil water subjected to the different mulch covers was found in the order of straw>sawdust>ash>no mulch. The variation on the soil moisture retention was found similar order in both days of measurement (i.e. 29 and 59 DAS). However, the amount of soil moisture irrespective of the treatments was found about 2-3% lower at latter date.

Shoot height: Following the seedling emergence, the crop height linearly increased up to 60 DAS followed by a lull phase towards maturity (Fig. 3). The different mulch covers played significant role on the crop height. The crop grown with sawdust mulch exhibited as tallest plant followed by

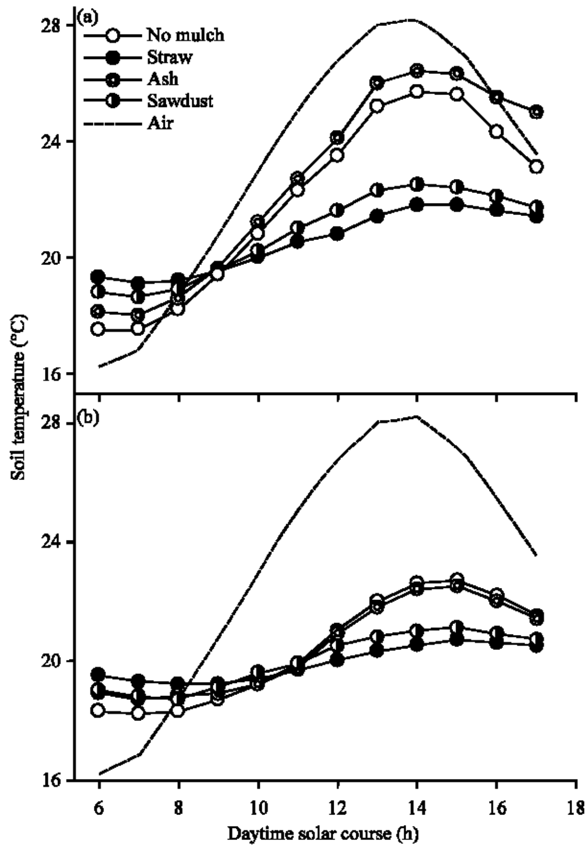

Fig. 1(a-b): Daytime-course of soil temperature at (a) 5 and (b) 10 cm depths subjected to different mulches on 10 December 2008 (29 DAS)

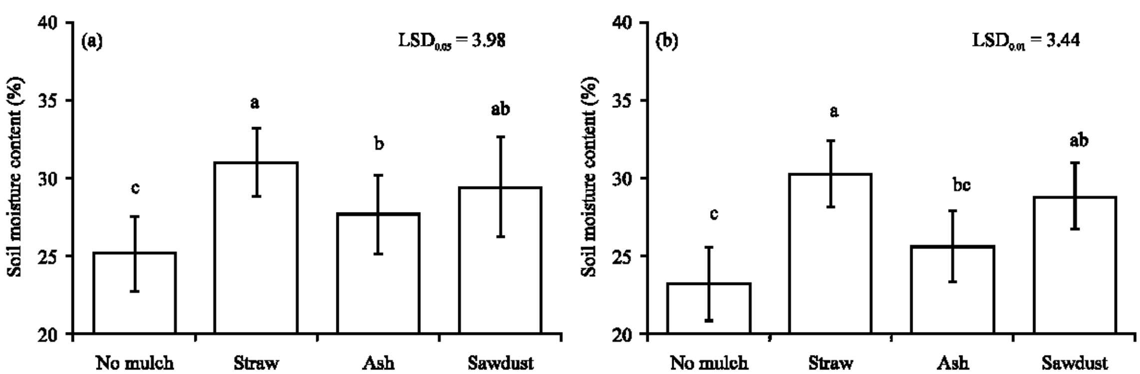

Fig. 2(a-b): Gravimetric moisture content (weight basis) of soil at 5-15 cm depth subjected to different mulches on (a) 10/12/2008 (29 DAS) and (b) 09/01/2009 (59 DAS). Vertical bars represent the standard deviation (SD, ±) of treatment mean (n = 4). Means followed by similar letters do not differ significantly at $p<0.05$ (a) or $p<0.01$ (b). LSD: Least significant difference

ash mulch whereas that growth with straw mulch produced the shortest plant. Overall, the crop heights under the different treatments appeared in the order of sawdust>ash>no mulch>straw.

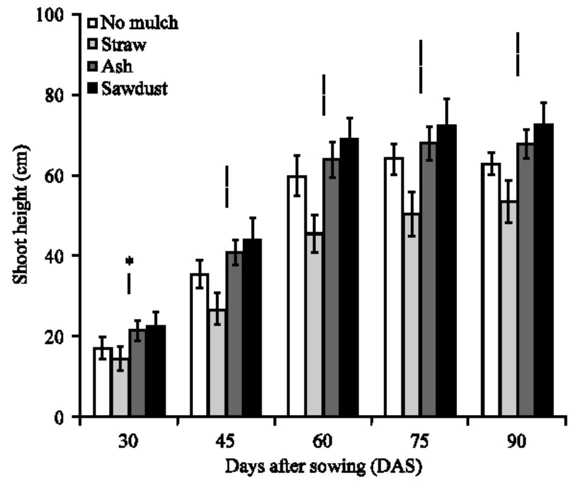

Fig. 3: Time-course of shoot height of mustard under different mulch covers. Attached vertical bars represent the standard deviation (SD, ±) of treatment mean (n = 4) whereas detached bars indicate the least significance difference (LSD) at $p<0.01$ (*$p<0.05$)

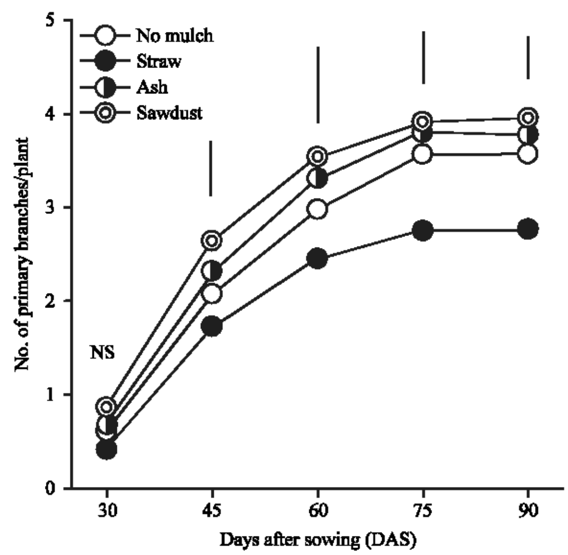

Fig. 4: Time-course of number of primary branches per mustard plant subjected to the different mulch covers. The vertical bars represent the least significance difference (LSD; $p<0.01$). NS: Not significant

Number of primary branches per plant: After crop emergence, there was only a few numbers of branches on main stem which rapidly increased up to 45 DAS (Fig. 4). Thereafter the number of primary branches per mustard plant slowly increased till 60 DAS followed by no increment towards maturity of crops. There was no significant effect of mulch covers on the number of primary branches/plant following the crop emergence. However, during the subsequent development, mulching treatments have played vital role for the variation of number of primary branches per plant. The mustard crop grown with sawdust mulch exhibited highest number and the crop grown with straw mulch exhibited lowest number of primary branches per plant. The magnitude of the number of primary branches per plant was found in the order of sawdust>ash>no mulch>straw.

Leaf Area Index (LAI): After seedling establishment, there was a minimum LAI which rapidly increased to get peak value on 60 DAS (Fig. 5). Thereafter, the LAI drastically declined towards maturity of crop. Mulching treatments had significant effect on the LAI development until about its peak value i.e. till 60 DAS. The mustard crop grown with sawdust mulch developed higher LAI followed by ash cover. In contrast, the crop grown with straw cover evolved minimum LAI while the crop with no mulch treatment ranked intermediate. Irrespective of the mulch covers, the mustard crop grown with minimum LAI at the later part of its development (following the peak LAI) when inter treatment variation was almost leveled-off.

Total dry matter accumulation: The dry matter accumulation within the entire plant is considered as biological yield of a crop community. The total dry weight estimated from 30 DAS to maturity of crop at an interval of 15 days and the data are presented in Fig. 6. Initially there was a small amount of dry matter accumulation in crop stands which rapidly increased until about 75 DAS followed by a little increment towards maturity. The effect of different mulch covers on the total biomass accumulation was found significant ($p<0.01$). The crop stands grown with sawdust and straw mulch covers accumulated significantly higher and lower amount of dry weight, respectively, while the effect of ash or no mulch (bare soil) covers ranked intermediate.

Yield components and yield: All the yield components which are directly responsible for yield formation of mustard crop were estimated at physiological maturity. The yield components like number of siliqua/plant, seed/siliqua and seed/plant, 1000-seed weight, seed weight/plant and yield are presented in Table 1. The crop stands grown with sawdust and straw mulching, respectively

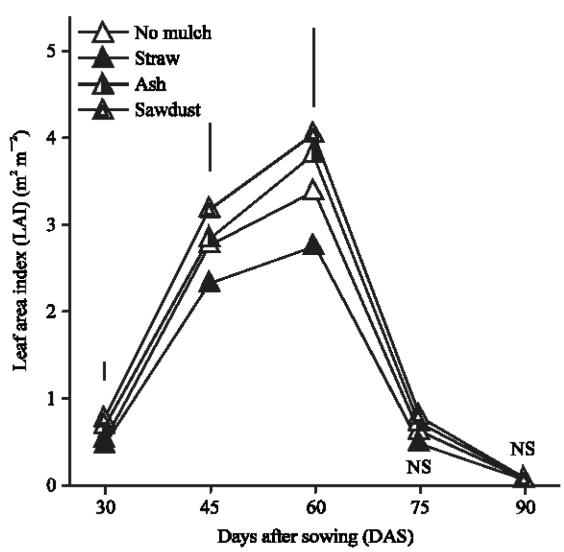

Fig. 5: Time-course of leaf area index (LAI) of mustard crop grown with different mulch covers. The vertical bars represent the least significance difference (LSD; $p<0.01$). NS: Not significant

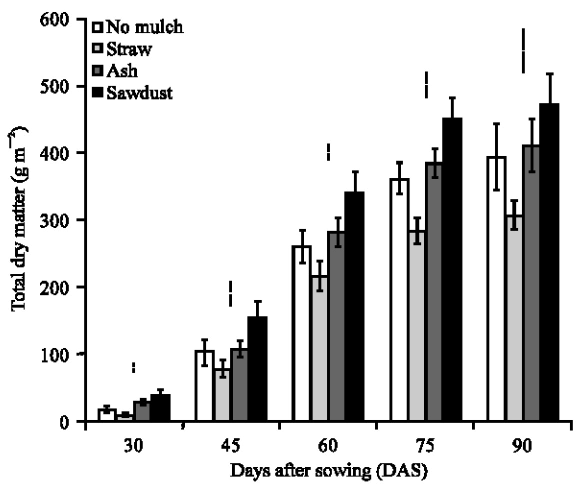

Fig. 6: Time-course of total dry matter accumulation in mustard crop subjected to the under different mulches covers. Attached vertical bars represent the standard deviation (SD, ±) of treatment mean (n = 4) whereas detached bars indicate the least significance difference (LSD; $p<0.01$)

Table 1: Yield components and yield of mustard plants as influenced by the different mulches

Treatments/ mulches	No. of siliqua plant^{-1}	No. of seed siliqua^{-1}	No. of seed plant^{-1}	1000-seed wt (g)	Seed wt plant^{-1} (g)	Seed yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
No mulch	49.2±3.6^{a}	23.4±1.5	1151±105^{b}	2.68±0.05	3.1±0.3^{b}	1.24±0.13^{b}	3.92±0.50^{b}	31.6±1.7
Straw	42.2±2.9^{b}	22.7±1.4	959±95^{c}	2.61±0.06	2.5±0.2^{c}	1.00±0.07^{c}	3.06±0.20^{c}	32.7±2.3
Ash	50.2±3.8^{a}	23.7±1.9	1189±87^{b}	2.69±0.07	3.2±0.2^{b}	1.28±0.06^{b}	4.10±0.40^{ab}	31.5±3.9
Sawdust	54.8±4.0^{a}	26.1±1.8	1427±112^{a}	2.70±0.06	3.9±0.4^{a}	1.54±0.14^{a}	4.71±0.45^{a}	32.8±3.1
$S_{\bar{x}}$	1.9	0.9	57	0.02	0.2	0.06	0.14	1.3
LSD	8.8	NS	263	NS	0.7	0.28	0.66	NS

Means followed by the same letter within a column do not significantly different ($p<0.01$). ±: Indicates standard deviation of treatment mean (n = 4), LSD: Least significant difference

exhibited the higher and lower values for all the yield components. However, the effect of different mulches on the number of siliqua/plant and seed/plant and seed weight/plant was found significant and the said effect on the number of seed/siliqua and 1000-seed weight was found non-significant.

The mean differences between the seed yield obtained from the treatments were found significant ($p<0.01$). The sawdust mulched crop stands produced (1.54 t ha^{-1}) about 35 and 20% higher seed yield than the crop stands grown with straw mulch or without mulch. The mean differences between the treatments for biological yield (i.e. total biomass production) were also similar as the differences obtained for the seed yield. The order of the magnitude for economic yield (i.e. seed yield) and biological yield (total dry matter yield) was found as sawdust>ash>control>no mulch. However, the effect of mulching on the variation of the harvest index was found insignificant.

DISCUSSION

Temperature in unmulched soil increases quickly with day progress due to the easy entrance of solar radiation. However, soil temperature under mulch covers depends on the nature of the mulch materials especially its spectral characteristics (Al-Karaghouli *et al.*, 1990). For example, a black body is a perfect radiation absorber while a white body is a perfect radiation reflector (Rosenberg *et al.*, 1983). Therefore, ash mulch absorbs maximum amount of light which is incident on it. It is also retained maximum heat itself but releases minimum towards the downstream. As a result, temperature at soil surface (i.e. 5 cm depth) which is close contact to the ash cover warms rapidly than the bare ground but the sub-surface layer (i.e. 10 cm depth) remains relatively cooler. The straw and sawdust covers act as white body property to incident radiation resulted the lowering soil temperature. Henceforth the magnitude of soil temperature at most of the daytime hours was found in the order of ash>no mulch>sawdust>straw covers for surface layer (i.e. 5 cm depth) and no mulch>ash>sawdust>straw for sub-surface layer (i.e. 10 cm depth). Similar order of soil temperature under different indigenous mulch covers were also reported by Awal and Ikeda (2002, 2003a, b) and Ramakrishna *et al.* (2006).

Mulch cover effectively protects the soil surface against evaporation (Singh *et al.*, 2011) by reducing the wind movement over it. It also isolates the solar radiation to ground keeping the soil cool. Therefore, soil moisture is effectively conserved under mulch covers especially straw or sawdust. The retention of soil water due to mulching is a common phenomenon in crop production which is being practiced from time immemorial in agriculture (Lal, 1978; Maurya and Lal, 1981; Abrecht and Bristow, 1990).

The ontogenic development of shoot height in this study follows the pattern of vertical development not only for mustard crop (Rahman *et al.*, 2009) but also the plant development of other crops like maize (Robertson, 1994; Mushagalusa *et al.*, 2008), barley (Awal *et al.*, 2007), sesame (Uzun and Cairgan, 2006), soybean (Willcott *et al.*, 1984) etc. Various mulches have regulatory effect on the plant height development for many crop species (Sandhu *et al.*, 1980; Wahba *et al.*, 1990; Csizinszky *et al.*, 1997; Anikwe *et al.*, 2007) but such effect is yet to be reported for mustard crop. Better vertical development of the mustard crop stands grown with sawdust mulch produced higher number of branches and thereby the greater leaf area index.

The seasonal time-course of LAI obtained in this study is very much common to the seasonal LAI of the other field crops (Katsura *et al.*, 2007; Gao *et al.*, 2009; Zhang *et al.*, 2009). The amount of dry matter accumulation indicates the overall performance of a crop in a given environment. Initially there is a small amount of dry matter accumulation which increased with season and maximum dry matter on physiological maturity at around the time of final crop harvest which is occurred for most of the herbaceous crops (Awal *et al.*, 2006; Namuco *et al.*, 2009; Uchino *et al.*, 2009; Kaewpradit *et al.*, 2009; Zhang *et al.*, 2009) including mustard (Rahman *et al.*, 2009). The dry matter accumulation and its seasonal trends in the mustard crop with present study exhibited the similar pattern. The sawdust mulched plants have been favoured for accumulating greater amount of dry matter might be due to its taller stature with greater number of branches and leaf area index. Therefore, the mustard crop grown with sawdust mulch cover exhibited the yield components with higher values and thereby higher yield. The finding regarding the mulching effects on the growth processes and yield potentials of mustard crop is yet to be reported. Hence, the results obtained from this study may be considered as pioneer information on underlying concept.

Mustard is a tropical as well as temperate crop and requires somewhat cool and dry weather for satisfactory growth. It requires a fair supply of soil moisture during the growing period and a dry clear weather at the time of maturity (Singh, 1983). Cool temperature, clear dry weather with plentiful of bright sunshine accompanied by adequate soil moisture increases the oil yield. Mustard crop is neither drought tolerant nor tolerates the water logging condition. These agro-climatic requirements of mustard crop allow its cultivation during winter season in Bangladesh. Therefore, cooler soil temperature along with higher amount of soil moisture induced by sawdust mulch cover favoured the mustard crop stands for better growth and yield. Straw mulch cover is much perfect than the sawdust for providing such microclimates but this mulch acts as a physical barrier for successful emergence of plantlets as the mustard seedlings are very much soft and succulent. Indeed many mustard plants in this study grown with straw cover were malformed and did not stand as a good crop. In addition to the data presented in this paper, our visual observation from frequent visits to the experimental site may also substantiate this assertion. Therefore, mustard crop is quite unsuitable with heavy mulch like straw cover although it fulfills the best microclimatic demands for this crop. In contrast loose or powder mulch like sawdust is quite suitable for easy seedling emergence along with good crop establishment resulted better growth and yield of mustard.

CONCLUSION

It is concluded from the present study that sawdust mulch provides better microclimate i.e. reduces temperature but increases the moisture content of the soil which might be considered for better growth and yield of mustard. If there is a locality where sawdust is cheaply available mustard production can be boosted with aforesaid practice.

REFERENCES

Abrecht, D.G. and K.L. Bristow, 1990. Maize seedling response to the soil environment at varying distances from a mulched soil-bare soil boundary. Soil Tillage Res., 15: 205-216.

Al-Karaghouli, A., A.W. Al-Kayssi and A.M. Hasson, 1990. The photometric properties of different colored plastic mulches used for soil solarization. Solar Wind Technol., 7: 119-123.

Anikwe, M.A.N, C.N. Mbah, P.I. Ezeaku and V.N. Onyia, 2007. Tillage and plastic mulch effects on soil properties and growth and yield of cocoyam (*Colocasia esculenta*) on an ultisol in southeastern Nigeria. Soil Tillage Res., 93: 264-272.

Awal, M.A. and T. Ikeda, 2002. Effects of changes in soil temperature on seedling emergence and phenological development in field-grown stands of peanut (*Arachis hypogaea*). Environ. Exp. Bot., 47: 101-113.

Awal, M.A. and T. Ikeda, 2003a. Controlling canopy formation, flowering, and yield in field-grown stands of peanut (*Arachis hypogaea* L.) with ambient and regulated soil temperature. Field Crops Res., 81: 121-132.

Awal, M.A. and T. Ikeda, 2003b. Effect of elevated soil temperature on radiation-use efficiency in peanut stands. Agric. For. Meteorol., 118: 63-74.

Awal, M.A., H. Koshi and T. Ikeda, 2006. Radiation interception and use by maize/peanut intercrop canopy. Agric. Forest Met., 139: 74-83.

Awal, M.A., M.H.R. Pramanik and M.A. Hossen, 2007. Interspecies competition, growth and yield in barley-peanut intercropping. Asian J. Plant Sci., 6: 577-584.

Cadavid, L.F., M.A. El-Sharkawy, A. Acosta and T. Sanchez, 1998. Long-term effects of mulch, fertilization and tillage on cassava grown in sandy soils in northern Colombia. Field Crops Res., 57: 45-56.

Csizinszky, A.A., D.J. Schuster and J.B. Kring, 1997. Evaluation of color mulches and oil sprays for yield and for the control of silverleaf whitefly, *Bemisia argentifolii* (Bellows and Perring) on tomatoes. Crop Protec., 16: 475-481.

Decoteau, D.R., M.J. Kasperbauer, D.D. Daniels and P.G. Hunt, 1988. Plastic mulch colour effects on reflected light and tomato plant growth. Sci. Hort., 34: 169-175.

Faget, M., M. Liedgens, B. Feil, P. Stamp and J.M. Herrera, 2012. Root growth of maize in an Italian ryegrass living mulch studied with a non-destructive method. Eur. J. Agron., 36: 1-8.

Gao, Y., A. Duan, J. Sun, F. Li, Z. Liu, H. Liu and Z. Liu, 2009. Crop coefficient and water-use efficiency of winter wheat/spring maize strip intercropping. Field Crops Res., 111: 65-73.

Gill, K.S., P.R. Gajri, M.R. Chaudhary and B. Singh, 1996. Tillage, mulch and irrigation effects on corn (*Zea mays* L.) in relation to evaporative demand. Soil Tillage Res., 39: 213-227.

Glab, T. and B. Kulig, 2008. Effect of mulch and tillage system on soil porosity under wheat (*Triticum aestivum*). Soil Tillage Res., 99: 169-178.

Gomez, K.A. and A.A. Gomez, 1984. Statistical Procedures for Agricultural Research. 2nd Edn., John Willy and Sons, New York, pp: 139-240.

Kaewpradit, W., B. Toomsan, G. Cadisch, P. Vityakon and V. Limpinuntana *et al.*, 2009. Mixing groundnut residues and rice straw to improve rice yield and N use efficiency. Field Crops Res., 110: 130-138.

Katsura, K., S. Maeda, T. Horie and T. Shiraiwa, 2007. Analysis of yield attributes and crop physiological traits of Liangyoupeijiu, a hybrid rice recently bred in China. Field Crops Res., 103: 170-177.

Kumar, S. and P. Dey, 2011. Effects of different mulches and irrigation methods on root growth, nutrient uptake, water-use efficiency and yield of strawberry. Sci. Horticult., 127: 318-324.

Lal, R., 1978. Influence of within- and between-row mulching on soil temperature, soil moisture, root development and yield of maize (*Zea mays* L.) in a tropical soil. Field Crops Res., 1: 127-139.

Leblanc, H.A., P. Nygren and R.L. McGraw, 2006. Green mulch decomposition and nitrogen release from leaves of two *Inga* spp. in an organic alley-cropping practice in the humid tropics. Soil Biol. Biochem., 38: 349-358.

Maurya, P.R. and R. Lal, 1981. Effects of different mulch materials on soil properties and on the root growth and yield of maize (*Zea mays*) and cowpea (*Vigna unguiculata*). Field Crops Res., 4: 33-45.

Midmore, D.J., D. Berrios and J. Roca, 1986. Potato (*Solanum* spp.) in the hot tropics II. Soil temperature and moisture modification by mulch in contrasting environments. Field Crops Res., 15: 97-108.

Murungu, F.S., C. Chiduza, P. Muchaonyerwa and P.N.S. Mnkeni, 2011. Mulch effects on soil moisture and nitrogen, weed growth and irrigated maize productivity in a warm-temperate climate of South Africa. Soil and Tillage Res., 112: 58-65.

Mushagalusa, G.N., J.F. Ledent and X. Draye, 2008. Shoot and root competition in potato/maize intercropping: Effects on growth and yield. Environ. Exp. Bot., 64: 180-188.

Namuco, O.S., J.E. Cairns and D.E. Johnson, 2009. Investigating early vigour in upland rice (*Oryza sativa* L.): Part I. Seedling growth and grain yield in competition with weeds. Field Crops Res., 113: 197-206.

Rahman, M.M., M.A. Awal, A. Amin and M.R. Parvej, 2009. Compatibility, growth and production potentials of mustard/lentil intercrops. Int. J. Bot., 5: 100-106.

Ramakrishna, A., H.M. Tamb, S.P. Wani and T.D. Long, 2006. Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in Northern Vietnam. Field Crops Res., 95: 115-125.

Robertson, M.T., 1994. Relationships between internodes elongation, plant height and leaf appearance in maize. Field Crops Res., 39: 135-145.

Rosenberg, N.J., B.L. Blad and S.B. Verma, 1983. Microclimate: The Biological Environment. 2nd Edn., Wiley Interscience, New York, pp: 209-287.

Sandhu, B.S., S.S. Prihar and K.L. Khera, 1980. Sugarcane response to irrigation and straw mulch in a subtropical region. Agric. Water Manage., 3: 35-44.

Sharratt, B.S. and D.M. Glenn, 1988. Orchard floor management utilizing soil-applied coal dust for frost protection. Part I. Potential microclimate modification on radiation frost nights. Agric. For. Meteorol., 43: 71-82.

Singh, B., P.L. Eberbach, E. Humphreys and S.S. Kukal, 2011. The effect of rice straw mulch on evapotranspiration, transpiration and soil evaporation of irrigated wheat in Punjab, India. Agric. Water Manage., 98: 1847-1855.

Singh, C., 1983. Modern Techniques of Raising Field Crops. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, India, Pages: 523.

Stigter, C.J., 1984. Examples of mulch use in microclimate management by traditional farmers in Tanzania. Agric. Ecosys. Environ., 11: 173-176.

Sui, H.J., D.C. Zeng and F.Z. Chen, 1992. A numerical model for simulating the temperature and moisture regimes of soil under various mulches. Agric. For. Meteorol., 61: 281-299.

Uchino, H., K. Iwama, Y. Jitsuyama, T. Yudate and S. Nakamura, 2009. Yield losses of soybean and maize by competition with interseeded cover crops and weeds in organic-based cropping systems. Field Crops Res., 113: 342-351.

Uzun, B. and M.I. Cairgan, 2006. Comparison of determinate and indeterminate lines of sesame for agronomic traits. Field Crops Res., 96: 13-18.

Wahba, S.A., S.I.A. Rahman, M.Y. Tayel and M.A. Matyn, 1990. Soil moisture, salinity, water use efficiency and sunflower growth as influenced by irrigation, bitumen mulch and plant density. Soil Technol., 3: 33-44.

Willcott, J., S.J. Herbert and L. Zhi-Yi, 1984. Leaf area display and light interception in short-season soybeans. Field Crops Res., 9: 173-182.

Youkhana, A. and T. Idol, 2009. Tree pruning mulch increases soil C and N in a shaded coffee agroecosystem in Hawaii. Soil Biol. Biochem., 41: 2527-2534.

Zhang, H., Y. Xue, Z. Wang, J. Yang and J. Zhang, 2009. Morphological and physiological traits of roots and their relationships with shoot growth in "super" rice. Field Crops Res., 113: 31-40.