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EFFECTS OF DIFFERENT MULCHING TECHNIQUES ON SUGAR BEET PERFORMANCE UNDER SEMI-ARID SUBTROPICAL CLIMATIC CONDITIONS

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Abstract

Evaporation from soil surface is an important component of the water balance in irrigated agriculture. Mulching as an effective technique not only decreases soil moisture evaporation but can also act as a useful tool to suppress weed growth and thus create favorable environment for plants growth. In this study, the effects of different types of mulches on sugar beet performance (root yield, sugar content, sugar yield and water use efficiency) were investigated for two consecutive years in the famous Peshawar valley of Indus Basin of Pakistan. It is evident from the results that the application of surface mulches significantly enhanced all the yield components and water use efficiency by improving soil moisture status over no mulch treatment. Similarly, use of black polyethylene film mulch was found better compared to straw mulch. Overall, mulch treatments produced 11.96 to 19.45% higher root yield, 14.33 to 22.68% higher sugar yield, 2.35 to 3.78% higher sugar content, 17.68 to 34.97% higher root irrigation water use efficiency, 20.38 to 37.78% higher sugar irrigation water use efficiency, 17.07 to 30.68% higher root crop water use efficiency, and 19.57 to 33.53% higher sugar crop water use efficiency, respectively, when compared with No-Mulch treatment. The study thus revealed that the use of mulches has the potential to improve the land and water productivity of sugar beet in water limited areas.

Key words: Crop yield, Film mulch, Straw mulch, Root yield, Sugar yield and Water use efficiency.

Introduction

The unproductive evaporation from soil root zone is a major source of moisture loss in the world arid and semi-arid regions (Khamraev & Bezborodov, 2016). Consequently, more water is required for plants survival to avoid stress conditions. Minimizing this huge amount of irrecuperable losses of water is therefore very crucial and if achieved can play an important role in contributing soil moisture conservation for optimum crop growth in limited water regions (Kader *et al.*, 2017).

In order to reduce the evaporation rate, different factors that are accountable for soil moisture loss e.g., vapor pressure gradient, heat of evaporation and capillary rise, must be reduced by adopting suitable soil management techniques. Mulching is one of these techniques that can be effectively utilized for reducing the effects of these factors by modifying soil surface condition and thus reducing soil water loss through evaporation. This makes more water available for crop consumptive use (Ahmed *et al.,* 2007). Jalota (1993) reported that mulching can be used as an effective tool for preventing about 40 to 70% water loss by evaporation in dry areas. Beside from moisture conservation, mulching practices also have profound effects on the yield and yield contributing parameters (Ekinci & Dursun, 2009). Teame *et al*., (2017) observed 147 to 250% higher grain yield of sesame crop when it was planted under different organic mulching conditions compared to that produced under No-mulch. Lehar *et al*., (2017) reported that yield produced by potato crop under rice straw mulch was almost double compared to No-mulch. Arash (2013) observed 33% increase in bean yield under mulching compared to No-mulch. The effect of different types of colored plastic mulches on chilli growth and yield was evaluated by Ashrafuzzaman *et al*., (2011) and concluded that mulching are effective tools for enhancement of chilli production under tropical environment. They also concluded that the performance of black film mulch in terms of increased yield and weeds suppression was much better than other colored plastic mulches. The effect of mulch types was also investigated by Seyfi & Rashidi (2007) on yield and water use efficiency of cantaloupe. They noted the highest yield and water use efficiency for treatment to which irrigation water was applied under plastic mulch.

Mulching practices have pronounced effects on enhancing water use efficiency (WUE). Kader *et al*., (2017) reported that both plastic and straw mulches increased the water use efficiency by 79% and 58%, respectively, compared to bare soil. Based on six years experiments on rice crop in China, Wu *et al*., (2016) observed that the crop water use efficiency was increased by 70 to 80% and irrigation water use efficiency by 274% when the crop was raised under the plastic film mulch conditions compared to the traditional planting. Zegada-Lizarazuand Berliner (2010) reported that the WUE of furrow and drip-irrigated maize under polyethylene mulch was 45-64% higher compared to No-mulch treatments. Zhang *et al*., (2017) reported 21.1 to 22.8% higher WUE for film mulched sowing compared to traditional sowing method without mulch. Dang *et al*., (2016) studied the effects of polyethylene film mulch on crop performance of early-sown short-season spring maize. They found that crop growth under plastic film mulch was accelerated because of improved soil temperature that ultimately caused higher grain yield and better water use efficiency. According to Xu *et al.*, (2015), maize yield and water use efficiency under plastic mulch was much better than without mulch. Yaghi *et al*., (2013) observed 31 to 44% higher yield and 56% higher WUE for cucumber when it was planted under plastic mulch compared to No-mulch. The increased yield and WUE under plastic mulch may be attributed towards reduced soil evaporation and more favorable soil temperature, compared to bare soil planting. In another study, Jiang *et al.*, (2016) reported that polyethylene film mulching is a valuable tool for enhancing surface water availability in dry regions by preluding the dry soil layer formation during the maize early growth stage and thus obtaining increased WUE. Tegen *et al*., (2016) obtained significantly highest marketable yield for grass straw mulch, followed by black film and white plastic mulches, respectively. They observed the lowest yield for No-mulch plots. Artyszak *et al*., (2014) reported that different types of straw mulches increased the sugar beet root yield by 9.40 to 11.20% and sugar yield from 8 to 11.30% compared to No-mulch treatment. Zhao *et al*., (2014) reported that the positive effects of surface straw mulch in terms of salinity management, soil moisture conservation and plant growth are highest in comparison to No-mulch treatment. Similarly, Shen *et al*., (2012) reported that straw mulch could be an effective mean for enhancing maize production and WUE in arid regions.

Alongside the potential benefits of soil water conservation, better yield and higher water use efficiency, mulching also control weed infestation (Matković *et al*., 2015), improve soil texture (Nawaz *et al*., 2016), improve aeration, modify soil temperature (Ramakrishna *et al*., 2006), checking surface sealing and crusting of soil by protecting the top soil surface from raindrop splashes (Brant *et al.,* 2017), decreasing nutrient losses and increase the infiltration rate (Lalljee, 2013), and increase sediment deposition by enhancing roughness of soil surface (Donjadee & Tingsanchali, 2016; Gholami *et al.,* 2014).

Beside the enormous benefits of mulching practices, its effects on sugar beet yield components and water use efficiency are yet to be documented in detail for the semi-arid regions of Pakistan. Therefore, the current study objective was to investigate the effect of different mulching materials on sugar beet root yield, sugar content, sugar yield and water use efficiency, and compare the results with conventional practices under subtropical continental dry regions.

Materials and Methods

The experimental work of this study was performed at the experimental station of Sugar Crops Research Institute (SCRI), Mardan, Khyber Pakhtunkhwa (KP), Pakistan, for two successive years during the cropping seasons of 2011-12 and 2012-13. The research site is located at alluvial valleys of Peshawar and Mardan plains, experiences subtropical, continental, semi-arid climate, with less than 500 mm mean annual rainfall and the annual evaporation demands is around 1500 mm (Malik *et al.,* 2017). The experimental design arrangement was randomized complete blocks with three replicates to evaluate the different mulching types. Hydrometer method was used for determination of soil texture class. Clay was found to be the dominant texture for the entire experimental field. Soil moisture constants (i.e. Field Capacity and Permanent Wilting Point) of collected field samples were determined in laboratory with a wide range pF meter DIK-3400 (pF 1.0 to 4.2). Bulk density (g cm^{-3}) of soil was found according to the guidelines of the United States Salinity Laboratory Staff, Anon., (1954).

Research site was divided into plots. Three types of mulching were used: black polyethylene film mulch (BPFM) (black with 100 microns thickens), the straw mulch (SM) and No-mulch (NM). In both study years, sugar beet variety Kaweterma was manually sown in November and harvested in the last week of May. Fertilizers potassium, phosphorus and nitrogen were applied at the rate of 75, 100 and 120 kg ha^{-1}, respectively. Full doze of phosphorus and potassium fertilizers and two-third of the nitrogen were applied to dry soil before making the ridges and beds, and mixed with the soil using cultivator. The second doze of nitrogen was applied before the ridges earthen up. For achieving ideal plant density (100,000 plant ha^{-1}), two hand thinning was carried out, one each at the four and six leaf stages, thus leaving one healthy plant per hill.

For better germination, light irrigation was applied to all the plots just after seeding, and then each field was regularly irrigated at 14-days interval considering the precipitation, temperature and soil moisture. Irrigation was stopped about 30 days before harvesting, however light irrigation was applied two days before harvesting with the purpose to facilitate the eradication process. Upon maturity, the crop was harvested manually by first separating the root-tops and then the roots were eradicated. Fresh yields of leaves and roots were independently weighed using electronic balance. The values were recorded in terms of kg $plot^{-1}$ and then converted to tons ha^{-1}. Sugar content analysis for each experimental plot was found analytically using the facilities available in the SCRI laboratory. Percent sugar content was then converted into tons ha^{-1} to obtain the sugar yield for each experimental unit. Root water use efficiency and sugar water use efficiency were separately determined using the model as mentioned by Tanner and Sinclair (1983).

Results and Discussions

Mulching effects on sugar beet root yield: Data in Table 1 shows that all the three mulching treatments i.e. No mulch (NM), black polyethylene film mulch (BPFM) and straw mulch (SM) significantly affected the root yield (at $p<0.05$). In both study years (2011-12 and 2012-13), maximum root yield (62.78 and 60.55 tons ha^{-1}) were observed for the BPFM treatment, followed by the SM (59.86 and 56.49 tons ha^{-1}). The lowest root yield (52.70, 48.77 tons ha^{-1}) was produced by NM treatment. Based on the two-year average values, it was noted that both the BPFM and SM treatments yielded 17.72 and 12.79% higher, respectively, compared to the NM treatment (Fig. 1). Percent increase in root yield by SM treatment in this study is in close agreement to the findings of Artyszak *et al*., (2014). They reported 9.4 and 11.2% higher yield when the crop was grown under different types of straw mulches compare to the conventional sowing without mulch. In another study, Shock *et al*., (1986) reported that the application of straw mulch increased the sugar beet root yield by 25% compared to that produced by No-mulch. The positive effects of mulching in terms of increased crop yield were also reported by other researchers for crops other than sugar beet. Luo *et al*., (2018) found that average grain yield of wheat was significantly increased (13.70%) by plastic film mulch compared to the NM treatment. Tegen *et al*., (2016) noted that average grain yield of winter wheat was increased by 28.0% under the SM treatment and by 13.7% under the plastic film mulch. Accordingly, Teame *et al*., (2017) observed 59.60 to 71.40% higher yield of sesame when it was grown under different kinds of mulches compared to the NM treatment. Godawatte & De Silva (2016) reported 4.61 to 8.24% higher yield of red okra under different organic mulches compared to the NM treatment. However, findings in the current study contradict in terms of increased yield from those obtained by Perez *et al*., (2004) for onion crop. They concluded that sweet onion decreased the yield by 7–60% when it was raised under the SM or BPFM compared to the NM treatment. Higher yield under bare soil conditions compared to the SM or BPFM may be attributed to the availability of root zone temperature closer to the optimum seasonal temperature. The findings from the current study also revealed that the BPFM treatment is more efficient in terms of increased yield compared to the SM. Similar results were also reported by Kader *et al*., (2017) for soybean, Berihun (2011) for tomato, Iftikhar *et al*., (2011) for chilli, and Ramakrishna *et al.,* (2006) for groundnut. The higher yield produced under the BPFM may be due to its effective soil moisture conservation, weed control, favorable soil temperature and micro climate modification. However, some contradictory results were reported by Nwosisi *et al*., (2017) for organic sweet potato and by Tegen *et al*., (2016) for tomato. They concluded that yield enhances under the SM treatment compared to the BPFM treatment.

Mulching effects on sugar beet sugar content: Table 1 further shows that, the application of different mulching techniques, significantly affected (at $p<0.05$) percent sugar content in sugar beet. In both study years, the highest amount of sugar content (16.35 and 16.25%) was observed in the BPFM treatment, followed by the SM (16.20 and 16.0%). The lowest sugar content (15.82 and 15.54%) was observed for the NM treatment. Overall increase observed in sugar content was 3.51% higher for treatment under the BPFM and 2.61% for the SM compared to the NM treatment (Fig. 1). Percent increase in sugar content due to the BPFM or SM effect observed in this study agrees to other studies reported from different parts of the world for different crops. Helaly *et al.* (2017) observed that the black film mulching and white film on black increased the sugar content in *Physalis pubescens* by an amount 8.10% and 38.20%, respectively compared to the bare soil planting. Parmar *et al*., (2013) reported that different kinds of color mulches increased the sugar content in water melon from 12.76 to 23.77%, and wheat straw mulch by 11.84% compared to the NM treatment. Shock *et al.* (1986) reported that straw mulch increased the sugar content in sugar beet by 6.21%. The improvement in sugar content due to mulching may be due to the promotion effect in plant growth and metabolic process, which reflected an increasing chemical composition as suggested by Helaly *et al*., (2017). However, results of the current study are in contrast to that reported by Adamavičienė *et al*., (2009). They concluded that the increase in sugar content in sugar beet under the SM was non-significant compared to the NM treatment.

Mulching effects on sugar beet sugar yield: Table 1 also presents the effects of different mulching practices on sugar yield of sugar beet. It was noted that mulching practices significantly improved the sugar yield during both the study years (2011-12 and 2012-13). The highest values (10.21, 9.70 tons ha^{-1}) were observed for treatment under BPFM, followed by SM (9.63 and 8.95 tons ha^{-1}). The lowest values (8.25 and 7.50 tons ha^{-1}) were observed for the NM treatment. Averaging the effect of two years, both the BPFM and SM produced 20.88 and 15.18% higher sugar yield, respectively, compared to that produced under the NM treatment (Fig. 1). The improvement in sugar yield exhibited in the current study is also supporting the findings of Artyszak *et al*., (2014). They observed 8 to 11.3% higher sugar yield when the sugar beet crop was grown in mulched condition compared to the NM treatment.

Mulching effects on irrigation water use efficiency: Mulching practices produced significant affects (at $p<0.5$) both on root irrigation water use efficiency (RIWUE) and sugar irrigation water use efficiency (SIWUE) (Table 2). Comparing the mean data of all treatments, the highest RIWUE (15.71 and 16.50 kg m^{-3}) during the study period were observed for the BPFM treatment. This was followed by the SM with 13.61 and 13.05 kg m^{-3}. The lowest values (10.71 and 10.73 kg m^{-3}) were obtained for the NM treatment. The SIWUE values were also highest for the BPFM (2.61 and 2.70 kg m^{-3}), followed by SM (2.23 and 2.11 kg m^{-3}) and NM (1.71 and 1.68 kg m^{-3}), respectively. The two years average SIWUE obtained was 33.46% for the BPFM and 19.58% for the SM treatment (Fig. 2). The positive effects of mulching on water use efficiency are also supported by Zhang *et al*., (2014) for maize crop, Hussain (2015) for common beans and Alenazi *et al.,* (2015) for muskmelon.

Mulching effects on crop water use efficiency (CWUE): Table 3 depicts that both the root crop water use efficiency (RCWUE) and sugar crop water use efficiency (SCWUE) were significantly (at $p<0.05$) affected by all the three mulching practices. In both study years, the highest RCWUE (10.96 and 10.30 kg m^{-3}) observed under the BPFM treatment, followed by SM (9.66 and 8.61 kg m^{-3}). The NM exhibited the lowest values (7.79 and 7.14 kg m^{-3}). Similarly, the highest SCWUE (1.80 and 1.67 kg m^{-3}) in two seasons were obtained for the BPFM treatment, followed by SM (1.57 and 1.38 kg m^{-3}) and NM (1.24 and 1.11 kg m^{-3}), respectively (Table 3).

Table 1. Root yield, sugar content and sugar yield of sugar beet as affected by different mulching practices.

Mulch types	Root yield (Tons ha^{-1})			Sugar content (%)			Sugar yield (Tons ha^{-1})		
	2011-12	2012-13	Average	2011-12	2012-13	Average	2011-12	2012-13	Average
NM	52.70c[1]	48.77c	50.74c	15.82c	15.54c	15.68c	8.25c	7.50c	7.88c
BPFM	62.78a	60.55a	61.67a	16.35a	16.25a	16.30a	10.21a	9.70a	9.96a
SM	59.86b	56.49b	58.18b	16.20b	16.0b	16.10c	9.63b	8.95b	9.29b

Note: [1]Mean followed by the same letter(s) are statistically non-significant at 1% probability
NM: No mulch, BPFM: Black polyethylene film mulch, SM: Straw mulch

Table 2. Mulching effects on root and sugar irrigation water use efficiency of sugar beet.

Mulch type	RIWUE (kg m^{-3})			SIWUE (kg m^{-3})		
	2011-12	2012-13	Average	2011-12	2012-13	Average
NM	10.71c[1]	10.73c	10.72c	1.71c	1.68c	1.69c
BPFM	15.71a	16.50a	16.11a	2.61a	2.70a	2.65a
SM	13.61b	13.05b	13.33b	2.23b	2.11b	2.17b

Note: [1]Mean followed by the same letter(s) are statistically non-significant at 5% probability

Table 3. Mulching effects on root and sugar crop water use efficiency of sugar beet.

Mulch type	RCWUE (kg m^{-3})			SCWUE (kg m^{-3})		
	2011-12	2012-13	Average	2011-12	2012-013	Average
NM	7.79c[1]	7.14c	7.64c	1.24c	1.11c	1.17c
BPFM	10.96a	10.30a	10.63a	1.80a	1.67a	1.74a
SM	9.66b	8.61b	9.13b	1.57b	1.38b	1.47b

Note: [1]Mean followed by the same letter(s) are statistically non-significant at 5% probability

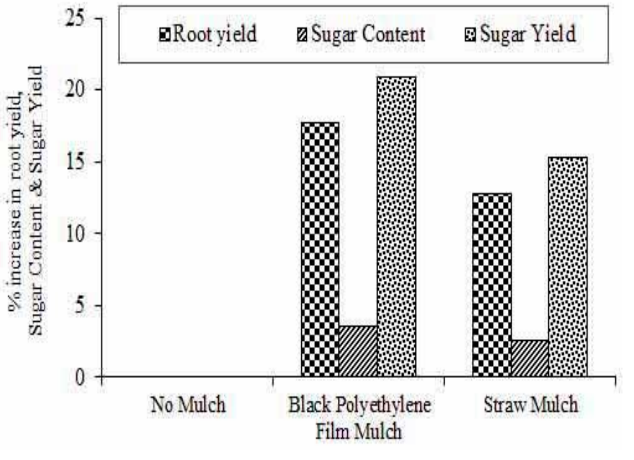

Fig. 1. Percent increase in sugar beet root yield, sugar content and sugar yield.

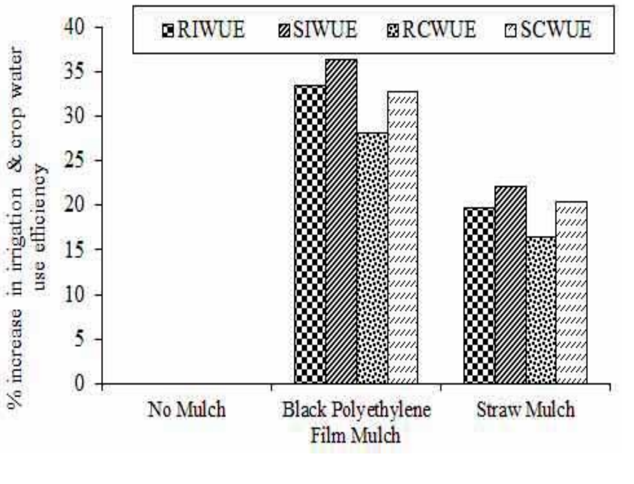

Fig. 2. Percent increase in sugar beet root and sugar irrigation water and crop water use efficiency caused by black film mulch and straw mulch treatments relative to No mulch.

Combining the effect of two years, it was observed that the BPFM and SM treatments increased the RCWUE by 28.13% and 16.32%, and the SCWUE by 32.71% and 20.41%, respectively compared to the NM treatment (Fig. 2).The relatively low WUE noted for the NM treatments may be due to the uninterrupted supply of solar radiation that reached the earth surface and thus increased the amount of non-beneficial evaporation and ultimately led towards lower water use efficiency as observed by Mukherjee *et al*., (2010). In contrary, mulch acted as a barrier between soil surface (evaporating site) and microclimate that caused reduction in vapor pressure gradient, and thus minimized the soil moisture loss through evaporation (Sarkar & Singh, 2007). The positive effects of mulches in terms of improved WUE were also reported by Ma (1999) and Xie *et al*., (2005) for wheat crop. Furthermore, the relatively lesser enhancement in WUE under the SM treatment in comparison to BPFM may be due to the weeds growth in the SM plots that forced the crop to compete for moisture and nutrient uptake. Whereas the highest WUE under the BPFM may be attributed to the notable reduction in evaporation along with the zero weeds growth that helped in maintaining higher moisture content in the crop root zone. Furthermore, the BPFM treatment helps in creating favorable environment around the root zone by accelerating its thermal status, reducing diurnal variation during winter season, steady movement of soil moisture and ultimately greater root penetration in the soil (Sarkar & Singh, 2007).

Conclusions

Findings from the current study revealed that all the yield and water use efficiency components were significantly (at $p < 0.05$) affected by all the mulching practices with the highest values observed for the BPFM treatments, followed by the SM and the least for the NM treatments. Under the BPFM treatment, the average root yield was increased by 17.72%, sugar yield by 20.88%, sugar content by 3.51%, RIWUE by 33.46%, SIWUE by 36.23%, RCWUE by 28.13% and the SCWUE by 32.76%, respectively compared to the NM treatment. Similarly, under the SM treatment, the root yield increased by 12.79%, sugar yield by 15.18%, sugar content by 2.61%, RIWUE by 19.58%, SIWUE by 22.12%, RCWUE by 16.32% and the SCWUE by 20.41%, respectively, compared to NM treatment. From these results, it is evident that soil mulching could be a better water-saving cultivation technique in water scarce areas.

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