Research Article

Integration of Compost and Salicylic Acid–Micronutrients Consortia with Conventional Fertilizers to Alleviate Heat Stress on Nutrient Use Efficiency, Yield and Quality of Cotton

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Abstract | Gradual climate changes has delayed wheat harvesting and monsoon arrival in Pakistan and thus, cotton sowing in Pakistan particularly in Southern Punjab cannot be completed in time. Late sown cotton faces problem of heat stress at reproductive growth stages which results in significant reduction of yield with poor fiber quality. Additionally, soil health of Pakistani soils is very poor due to low soil organic matter, non-judicial use of fertilizers and high cropping intensity with mono-cropping pattern. The integrated and judicial use of organic and synthetic fertilizers boosts the soil and plant health and mitigates the deteriorative effects of heat stress on plants. Based on past studies, the objective of the study was to integrate pre-tested compost, SA, Zn-Fe-B consortia and foliar K with conventional fertilizers for ameliorating detrimental effects of heat stress on morphological and fiber characteristics of cotton. During study, salicylic acid based Fe, Zn, B consortia (S-N consortia), foliar potassium (K) and compost were used in different combinations along with conventionally used fertilizers. Nutrient Results reveal that integrated use of compost and S-N consortia improved yield attributes particularly fruit set percentage, flower to fruit conversion percentage, square boll size and weight, opening of square bolls and seed-cotton yield compared to conventional approach. Compare to farmer practice, foliar K application showed a significant increase in fiber quality parameters such as fiber length, fiber strength, MIC, micronaire and ginning out turn (GOT). Results advocate compost, micronutrients and K essential element of cotton production whenever cotton is under heat stress.

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Introduction

Cotton is considering white gold fiber in Pakistan (Rahman *et al*., 2007). Pakistan is the fifth–world largest cotton producer (Khalid *et al*., 2022). Pakistan economy largely depends on agriculture sector. Cotton contributes 10% to the national GDP compared to the overall agriculture sector GDP share of 19.2% (Azumah *et al*., 2019; Pakistan Economic Survey 2020-21). It is planted on about 3.19 million hectares producing 14.26 million bales with average seed-cotton yield of 760 kg ha^{-1}. Cotton contributes in export revenue as lint while its cottonseed meets 80% cooking oil demand (REF). About 77% cotton is cultivated in Punjab province alone and remaining 23% in other provinces (Chaudhry *et al*., 2009). Sowing time and selection of suitable genotypes are key factors of cotton yield. Both factors are crucial for cotton production (Jamil *et al*., 2022). The variety choice reflects yield, tolerance to unfavorable conditions and timely maturity of the crop. Too early sowing or very late sowing has adversely influenced yield potential (Feng *et al*., 2017).

Under changing climate, rise in temperature is one of the issues that could be considered the main environmental threat suppressing yielding potential of existing genotypes (Li *et al*., 2024). High temperature is the most critical factor affecting cotton yield from fertilization to harvest. Increased temperature, in particular, influences different biochemical and physiological processes associated with cotton plant, resulting in low seed cotton production (Ahmad *et al*., 2017; Abro *et al*., 2023). Cotton cultivars sown by 15th May are reported with better yields than the same cotton when planted in June (Jamil *et al*., 2022). Cotton is a crop of hot climate but has shown a significant reduction in production when temperature is reported over 30°C (Bibi *et al*., 2008). High temperature has adversely affected flower and boll development in late sown cotton as compared to an early planted crop (REF). The key reason of yield gap between actual and potential is environmental stress of the crop reproductive growth phase. Recent forecasting of global temperature rise is expected 4°C in the end of this century (Craufurd and Wheeler, 2009). Nevertheless, environmental heat stress at flowering and fruiting stages have shown adverse effects on many field crops with severe losses in yield and seed/fruits quality (Rai, 2020).

There are several ways to combat drawbacks of heat stress on crop. First approach is to mitigate heat stress by improving soil and plant health (Acosta-Martinez and Cotton, 2017). Soil health is closely linked with soil organic matter (SOM) and adequate SOM guarantees better soil and plant health. Novel approach to improve soil organic matter is the use of organic sources. Among organic sources, compost is of key importance as it is partially decomposed form of organic sources. Compost improves soil health as well as acts as a unique source of plant essential nutrients (Fauziah *et al*., 2009). It boosts up microbial activities in soil (Van Camp *et al*., 2004), replenishes the organic matter in soils (Tejada *et al*., 2009) and prevents leaching or fixation of nutrients particularly P and micronutrients (Larney *et al*., 2008).

Nutrient imbalances in plants have a significant impact on their performance, such as growth pattern, antioxidant defence mechanisms, and tolerance to biotic and abiotic stresses (Hajiboland, 2012; Kumari *et al*., 2022). Being principal inducers of oxidative stress in plants, these stresses burst reactive oxygen species (ROS) production that subsequently cause damage to plant cells and hinder the metabolic and physiological activities of a plant (Kumari *et al*., 2022). Zinc (Zn) nutrition facilitates better defense against heat stress by maintaining the membrane integrity inside the plant system (217), biosynthesis of proteins, and detoxification of superoxide radicals (Cakmak *et al*., 2023). Zn is an integral constituent of Cu-Zn-SOD, a ROS scavenger (217). The role of B in cell wall structure formation, sugar translocation, membrane integrity and plant reproductive growth is critical for reducing the damage caused by abiotic stress, particularly high-temperature stress (Waraich *et al*., 2012). Shahid *et al*. (2018) has reported that B application reduced the impact of high temperature on vegetative and reproductive stage of rice cultivars. Iron (Fe) is one of the chief components of the cell redox systems and also functions as a cofactor regarding various antioxidant enzymes such as CAT, POD and APX (Kumar *et al*., 2010; Venugopalan *et al*., 2021). Baghizadeh and Shahbazi (Baghizadeh *et al*., 2013) reported that foliar Fe nutrition with Zn reduces oxidative stress by accelerating antioxidant enzyme mechanisms (CAT, GPX and SOD). Baghizadeh *et al*. (2013) also reported that foliar spraying of B @ 0.2% + Fe @ 0.5% produced 58% and 27. % higher seed and stover yields than the control treatment apart from alleviating combined heat and moisture stress.

In addition to judicial use of nutrients, the exogenous application of suitable plant hormone also helps to ameliorate the effects of abiotic stresses on crops. Salicylic acid (SA) is a key regulator in orchestrating plant responses to abiotic stresses by activating plant defense system based on antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD), excellent scavengers of ROS (Loake and Grant, 2007). Hamani *et al.* (2020) reported that exogenous SA significantly ameliorated salinity stress in cotton by boosting the activity of glutathione reductase, ascorbate peroxidase, superoxide dismutase, catalase and peroxidase, with a significant decrease in malondialdehyde content.

Potassium (K) nutrition before onset of reproductive stage is of key importance due to pivotal role of K in upgrading the resilience of crops in response to the adversities of several abiotic stresses (Danial *et al*., 2010; Jan *et al*., 2017). Potassium prevents ROS accumulation in the cells (Soleimanzadeh *et al*., 2010) by virtue of activating a series of antioxidant enzymes such as SOD, POD, APX and CAT (Subbaramamma *et al*., 2017). Based on past studies reported by Yaseen *et al*. (2013), Arif *et al*. (2018) and Ahmed *et al*. (2020) and above facts in mind, a study was planned to integrate all findings of past studies for improving nutrient use efficiency, yield and fiber quality of cotton.

Materials and Methods

A field trial was conducted at the research area of Muhammad Nawaz Sharif- University of Agriculture, Multan (MNSUAM) to study the alleviated heat stress on late sown cotton using SA-Zn-Fe-B based consortia (S-N Consortia), K and P enriched compost as treatments with different combinations. The objective of the study was to come on declined yield and fiber quality of late sown cotton as significant improvements in seed-cotton yield and fiber quality.

Preparation of consortia and compost

Based on our past research trials, SA-Zn-Fe-B-consortia (S-N Consortia) was formulated using 0.3 mM SA (Ahmed *et al*., 2020) and 0.2% Zn, 0.2% Fe and 0.8% B solutions (Yaseen *et al*., 2013). Similarly, compost was also prepared by the same method used in our past study reported in 2018 (Arif *et al*., 2018). For compost, organic waste material collected from the university waste management site was used. The sorted and dried organic waste was crushed in a grinding unit of composter to convert raw form of waste into ground form and then was enriched with rock phosphate (RP) and enriched compost and incubated in a specially prepared Composter for six days (Arif *et al*., 2018).

Treatment plan and application

The experiment was laid down according to a randomized complete block design (RCBD) with four replicates. Treatment plan included seven treatments: Control (conventional NPK, T_1), soil application of compost @ 692 kg ha^{-1} (T_2), foliar application of S-N Consortia (T_3), foliar application of 2% K (T_4), compost + S-N Consortia (T_5), compost + K (T_6), and Compost +K + S-N Consortia (T_7). Equal quantity of conventional fertilizers i.e., N (120 kg ha^{-1}), P (90 kg ha^{-1}) and K (60 kg ha^{-1}) were used in all treatments. The used chemical sources for N, P and K were Urea, diammonium phosphate (DAP) and potassium sulfate (SOP). Compost was applied before seed sowing whereas foliar application of S-N Consortia and K were sprayed @ 1250 ml ha^{-1} at two stages; at the first irrigation after seed germination and 15 days of first spray. The field soil was of loam texture, deficient in P, alkaline and calcareous in nature and deficient in organic matter (Table 1).

Table 1: *Physico chemical properties of experimental soil.*

Parameter	Unit	Value
Textural class	-	Loam
Organic	%	0.49
ECe	dS m^{-1}	2.31
pH	-	8.00
CEC	$Cm_c kg^{-1}$	5.29
Total N	%	0.039
Available P	mg kg^{-1} soil	6
Extractable K	mg kg^{-1} soil	108

Nutrient uptake and nutrient use efficiency

Sampled leaves and petioles of cotton were oven dried till constant weight, ground and analyzed for macro nutrients as described by Wolf (1996). Nitrogen was analyzed according to Jackson (1962) while phosphorus by using vanadate-molybdate spectrophotometric procedure. Potassium was determined by flame photometer (Chapman and Pratt 1961). From the product of N, P and K concentrations and dry mass, uptake of each nutrient by cotton leaves and fertilizer use efficiency was calculated as described by Shahbaz *et al*. (2013).

Statistical analysis

All the data was analyzed using RCBD while means were compared using LSD test (Steel *et al*., 1997).

Results and Discussion

Gas exchange characteristics and water use efficiency

Data related to photosynthetic rate of cotton is graphically shown by Figure 1a. It is clear that effect of all the treatment on photosynthetic rate is statistically significant and all the treatments significantly affected the photosynthetic rate of cotton. Results show that minimum photosynthetic rate was observed in T_1 (control treatment) while spray of SA-micronutrients and K significantly accelerated the photosynthetic rate by mitigating the effect of late sowing on the cotton. An increase up to 34% was observed due to alone application of nutrient consortia over control treatment while comparatively, K application caused 45% improvement in photosynthetic rate. It was also found that about up to 45% increase in photosynthetic rate occurred due to combined spray of consortia and K which suggests that combined application of SA+Fe+B+Zn and K is more effective approach than alone application of K or SA-micronutrients (Figure 1). Similar Figure 1 also showed that SA+ compost is much better than alone SA while compost caused 10 to 60% improvement in photosynthetic rate. Data for transpiration rate in cotton is given in Figure 1b clearly elucidates that effect of all the treatment on transpiration rate was statistically significant. Figure 1b showed that SA+ compost is much better than alone SA while compost caused up to 22% improvement in transpiration rate. Results show that minimum transpiration rate was observed in T_1 (control treatment) while spray of SA-micronutrients and K significantly accelerated the transpiration rate by mitigating the effect of late sowing on the cotton. Up to 32% increase in transpiration rate was observed due to alone application of nutrient consortia over control treatment while up to 87% increase over control was observed due to K application.

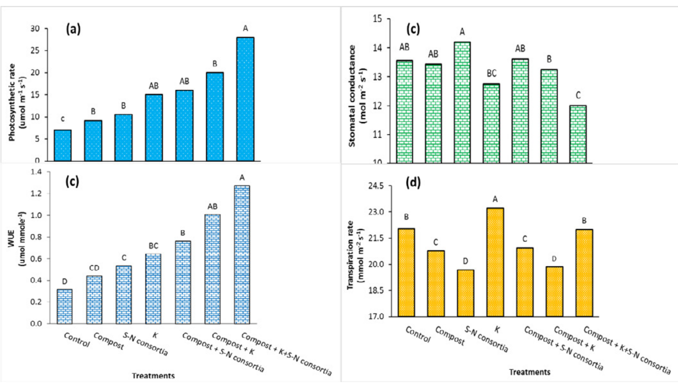

Figure 1: *Comparative effects of integrated compost, S-N Consortia and K application with conventional fertilizers on gas exchange characteristic and water use efficiency. Bars with same capital letter(s) are at par (p <5%) according to HSD test.*

Data related to stomatal conductance of cotton is graphically shown by Figure 1c. Results show that minimum stomatal conductance was observed in T_1 (control treatment) while spray of SA-micronutrients and K significantly accelerated the stomatal conductance by mitigating the effect of late sowing on the cotton. An increase up to 11% was observed due to alone application of nutrient consortia over control treatment while comparatively, K application caused 33% improvement in photosynthetic rate. It was also found that about up to 31% increase in stomatal conductance occurred due to combined spray of consortia and K which suggests that combined application of SA+Fe+B+Zn and K is more effective approach than alone application of K or SA-micronutrients (Figure 1). This also showed that SA+ compost is much better than alone SA while compost caused 10 to 60% improvement in photosynthetic rate.

Data related to WUE is graphically shown by Figure 1d clearly reflects that effect of all the treatment on WUE is statistically significant. Minimum WUE was occurred in T_1 (control treatment) while maximum WUE was observed in treatment where SA-micronutrients+K+ compost which was 35% more than control. Comparatively, K application resulted 25% more WUE than control while 33% more WUE was noted due to combined spray of consortia and K which suggests that combined application of S-N Consortia and foliar K is more effective approach than alone application of K or SA-micronutrients. Similar Figure 1d also showed that S-N consortia + compost is much better than alone S-N consortia while integration of S-N consortia, compost and foliar K caused 10 to 60% improvement in WUE compared to conventional approach of fertilizers.

Yield attributes

Data related to number of branches per cotton plant is shown by Figure 2.

Figure 3 reveals that there was significant change in number of flowers per plant and open bolls per plants.

Variations in seed cotton and fiber quality

Seed cotton yield: The effect of K, S-N consortia and compost on seed cotton yield is graphically shown by Figure 4. As compared to control, minimum seed cotton yield (SCY) were found in control treatment where only NPK fertilizers was applied alone. Following T_6 treatment, T_5 and T_7 showed an increase in seed cotton yield, which was 22% of seed cotton yield

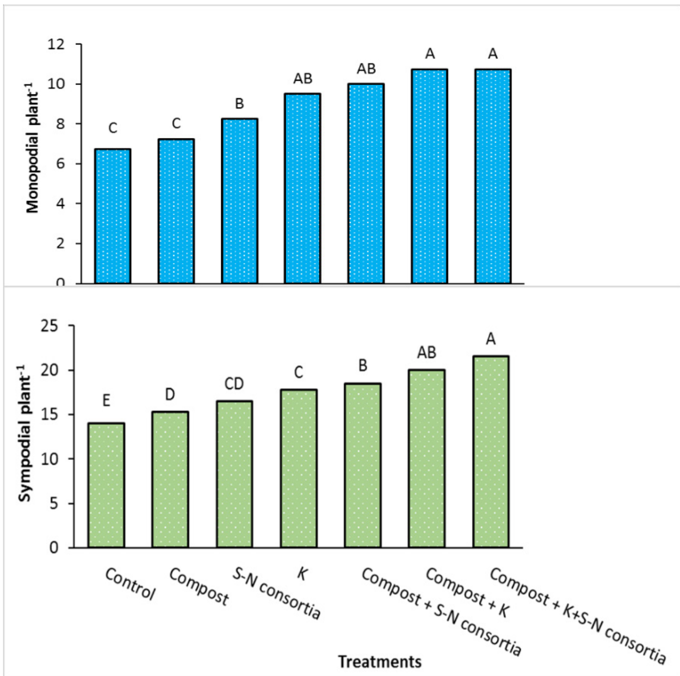

Figure 2: *Improvements in monopodial and sympodial branches of cotton due to integration of compost, S-N Consortia and K application with conventional fertilizers. Bars with same capital letter(s) are at par (p <5%) according to HSD test.*

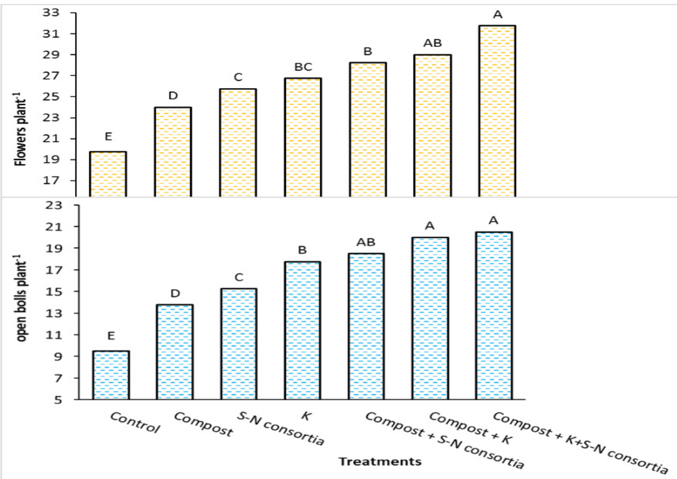

Figure 3: *Improvements in flowers and open bolls per cotton plant due to integration of compost, S-N Consortia and K application with conventional fertilizers. Bars with same capital letter(s) are at par (p <5%) according to HSD test.*

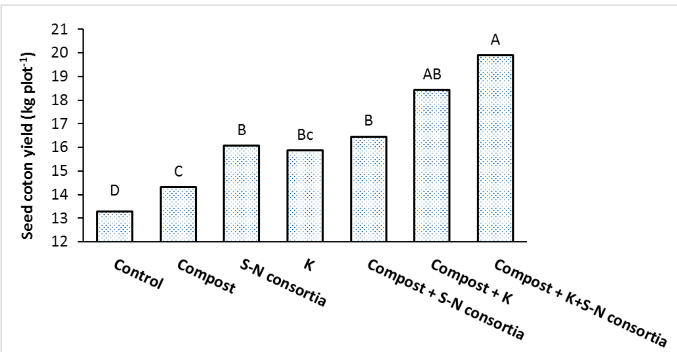

Figure 4: *Improvements in seed cotton yield due to integration of compost, S-N Consortia and K application with conventional fertilizers. Bars with same capital letter(s) are at par (p <5%) according to HSD test.*

compared to control treatment. In contrast to control, SA+Fe+B+Zn caused 6 to 18% more SCY. Exogenous SA notably improved growth of crops under stress, momentous improvements in net CO_2 assimilation and increased chlorophyll content (Martel and Qaderi, 2016). SA role in thermo tolerance (Ahammed *et al*., 2016), salinity tolerance (Li *et al*., 2017) by escalating proline accumulation, maintaining membrane stability, and biosynthesis of amino acids and carbohydrates (Li *et al*., 2017). Compared to T_1 treatment, K treatments caused 7 to 17% more SCY. Such changes in yields were also suggested by Ebrahimi *et al*. (2011). Data in Figure 4 also showed that application of SA+ compost is much better than alone application of SA. The increase in seed cotton yield might be due to better uptake of water and nutrients because acidified water lowers the soil pH which plays a significant role in plant nutrition. Alike K, compost also compost caused 6 to 15% more SCY as compost prevents leaching or fixation of nutrients (Larney *et al*., 2008).

Lint weight to seed weight

The alone and combined application of K, S-N consortia and compost significantly affected lint weight and seed weight (Figure 5). Results show that seed cotton of plants subjected to K, S-N consortia and /or compost application showed higher lint weight than seed weight compared (Figure 5). As compared to control, minimum lint weight was found in control treatment (T1). Following T_5 treatment, $T_7$and T_3 showed an increase in Lint weight, which was 27% of Lint weight compared to control treatment. The minimum lint weight was found in T_1 (control). The difference in Lint weight in different treatments was obvious as compared to control (T_1). Figure 3c also show that foliar spray of K application caused 8 to 18% more lint weight with respect to control. It also showed that application of SA+ compost is much better than alone application of SA. The increase in Lint weight might be due to better uptake of water and nutrients because acidified water lowers the soil pH which plays a significant role in plant nutrition.

Fiber length of cotton lint

The combined effect of K, S-N consortia and compost on fiber length of cotton lent is graphically shown by Figure 6a. As compared to control, minimum fiber length of cotton lent was found in control treatment (T1). Followed T_4 treatment, T_6 and T_7 showed an increase in fiber length of cotton lent, which 25% of fiber length of cotton was lent compared to control treatment. In contrast to control, S-N consortia caused 4 to 16% increase in fiber length of cotton lint while minimum fiber length of cotton lint was found in T_1 (control). Micronutrients particularly zinc (Zn), iron (Fe) and boron (B) play key role to combat effects of environmental stresses on growth of plants (Ahmed, 2009). With respect to control, foliar spray of K application caused 6 to 15% more fiber length of cotton lint. Such changes were also observed in literature because K is a macronutrient and its application is very important for crop productivity (Ebrahimi *et al*., 2011; Kadam *et al*., 2011) Data in Figure 6a also showed that use of S-N consortia +compost is greatly superior to alone application of S-N consortia. The increase in fiber length of cotton lint might be due to better uptake of water and nutrients because acidified water lowers the soil pH which plays a significant role in plant nutrition.

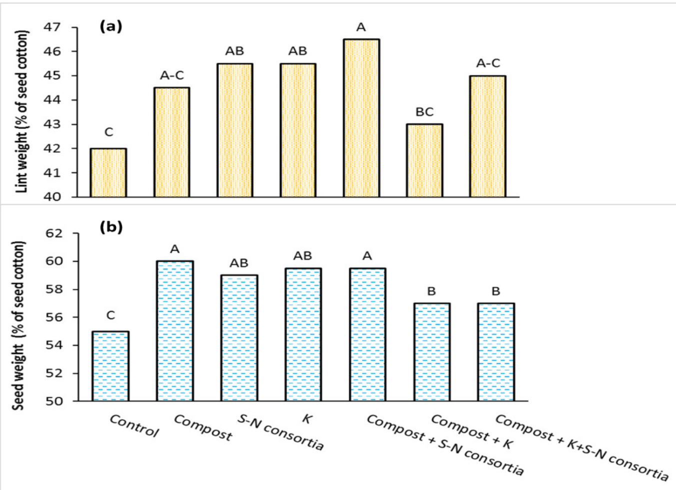

Figure 5: *Improvements in lint to seed weight induced by integration of compost, S-N Consortia and K application with conventional fertilizers. Bars with same capital letter(s) are at par (p<5%) according to HSD test.*

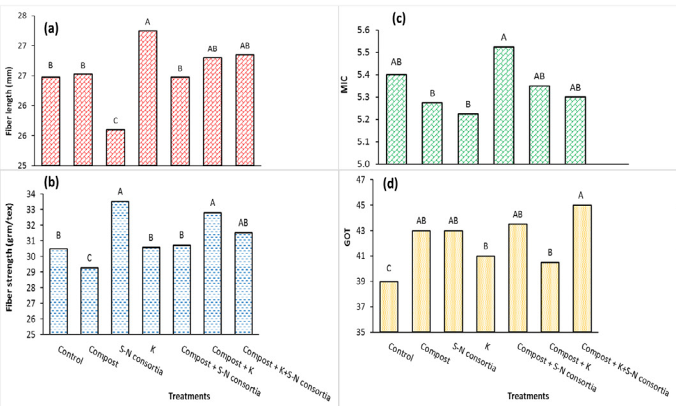

Figure 6: *Comparative variations in seed-cotton fiber quality parameters as result of integration of compost, S-N Consortia and K with conventional fertilizers. Bars with same capital letter(s) are at par (p <5%) according to HSD test.*

Fiber strength of cotton lint

The comparative effect of K, S-N consortia and compost on fiber strength of cotton lent is shown by Figure 6b. As compared to control, minimum fiber strength of cotton lent was found in control treatment (T1). Following T_3 treatment, T_6 and T_7 showed an increase in fiber strength of cotton lent, which was 13% of fiber length compared to control treatment. In contrast to control, S-N consortia caused 4 to 10 % more fiber strength of cotton lent. SA role in thermo tolerance (Ahammed *et al*., 2016), salinity tolerance (Li *et al*., 2017) by escalating proline accumulation, maintaining membrane stability, and biosynthesis of amino acids and carbohydrates (Li *et al*., 2017). With respect to control, foliar spray of K application caused 7 to 17% more fiber strength. Likewise, Figure 3b presented the use of SA+ compost is much better than alone application of SA. The increase in fiber strength of cotton lent might strength be due to better uptake of water and nutrients because acidified water lower the soil pH which plays a significant role in plant nutrition.

MIC (fiber fineness (micronaire micro gram/inch)

Fiber fineness in dignified in micronaire, which unique cotton term associated to fiber maturity and fineness (diameter). It is the measurement of air flow tough through a 2.34g fiber sample that is compacted to a specific volume. Micronair can be altered to estimated desire value by dividing micronair value with 2.82. Fiber fineness was measured from lint sample of the selected plants from each genotype by using HVI. The proportional effects of K, S-N consortia and compost on MIC of cotton is shown by Figure 6c. As compared to control, minimum MIC was found in control treatment (T_1). Following T_4 treatment, $T_1$and T_5 showed an increase in MIC, which was 19% of MIC compared to control treatment. In contrast to control, S-N consortia caused 3 to 13% more MIC while K application instigated 8 to 19% more MIC. All these improvements occurred SA adjusts vital plant physiological processes such as photosynthetic rate (Miura and Tada, 2014). Compost boosts up microbial activities in soil (Van Camp *et al*., 2004). Moreover, it replenishes the organic matter in soils (Tejada *et al*., 2009) and prevents leaching or fixation of nutrients as compare to the chemical fertilizers (Larney *et al*., 2008). Like Kwong and Pasricha (2002) also reported that balance fertilization is necessary to get optimal produce and worth of sugarcane. Data in Figure 4 22 showed the use of SA+ compost is much better than alone application of S-N consortia. The increase in MIC might be due to better uptake of water and nutrients because acidified water lowers the soil pH which plays a significant role in plant nutrition. Findings of Asgharipour and Heidari (2011) also supports the finding of Kadam *et al.* (2011) because Asgharipour *et al.* (2011) also found substantial escalation in growth/yielding of sorghum due to adequate supply of K in the form of SOP compared to control under drought stress.

Ginning turn out (GOT= %)

The data related to qualified possessions of K, S-N consortia and compost on GOT percentage yield of cotton is graphically shown by Figure 6d. As compared to control, minimum GOT percentage yield were found in control treatment where only NPK fertilizers was applied alone. Following T_7 treatment, T_5 and T_3 showed an increase in GOT percentage yield, which was 15% of GOT percentage yield compared to control treatment. In distinction to control, S-N consortia caused 4 to 16% more GOT percentage yield while K application caused 6 to 17% more GOT percentage yield. Micronutrients particularly zinc (Zn), iron (Fe) and boron (B) play key role to combat effects of environmental stresses on growth of plants (Ahmed, 2009). The late sowing of crops possesses oxidative stress (Hussain *et al.*, 2018). SA adjusts thermo tolerance, salinity tolerance by adjusting proline accumulation, maintaining membrane stability, and biosynthesis of amino acids (Ahammed *et al.*, 2016; Li *et al.*, 2017). The increase in GOT percentage yield might be due to better uptake of water and nutrients because acidified water lowers the soil pH which plays a significant role in plant nutrition. These improvements are due to application of compost because compost improves soil health (Fauziah *et al.*, 2009), boosts up microbial activities (Van Camp *et al.*, 2004) and replenishes SOM (Tejada *et al.*, 2009) and soil fertility (Larney *et al.*, 2008). Razzaque *et al.* (2001) conducted two field studies and suggested K nutrition is essential for fruit quality of pineapple. They used K up to 1.33 tons ha^{-1} and found a close relationship between K dosage and fruit diameter of pineapple. Alike conclusions were also stated by Kwong and Pasricha (2002) who investigated the effect of K nutrition for sugarcane and suggest that sufficient amount of potassium fertilization should done for higher profitability of sugarcane. Like Kwong and Pasricha (2002) also reported that balance fertilization is necessary to get optimal produce and worth of sugarcane.

Nutrient contents

Leaf nitrogen, phosphorus and potassium contents: Variations in leaf N contents due to compost, S-N consortia and K application (Figure 7a) illustrate a clear cut difference among all the treatments. The difference was also statistically significant. Lowest leaf N contents were found in control treatment whereas largest leaf contents in treatment T_7 (compost, S-N consortia + K). Treatment T_7 was followed by T_4, and T_3, showing an increase in leaf N contents due to treatments over control treatment. About 12-23% increase in leaf N contents was recorded due to above mentioned treatments compared to control treatment. Results also suggested that combined application of compost, S-N consortia and K is better than alone application. S-N consortia caused 4 to 15% more shoot N contents which were lower than treatments containing their combined applications Figure 7a.

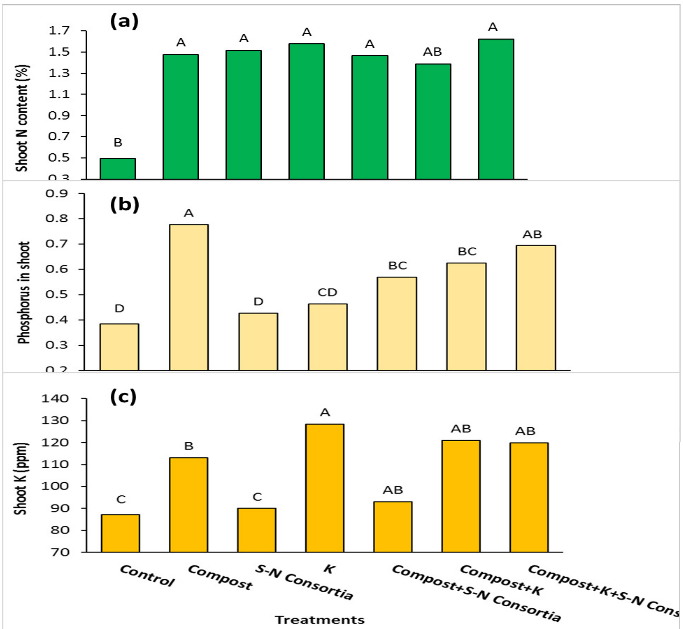

Figure 7: *Integrated effects of compost, S-N Consortia and K application on N, P and K contents of cotton shoot. Bars with same capital letter(s) are at par (p <5%) according to HSD test.*

Figure 7b reveals the variations in shoot P contents due to compost, S-N consortia and K application. Highest shoot P contents were found in treatment T_2 which was 18% whereas lowest shoot P contents were found in treatment T_1 (control). Treatment T_2 was followed by T_7, and T_6, with an increase of 12-23% in shoot P contents over control treatment. It shows that compost applied alone or K or S-N consortia or both effectively improved shoot P contents which might be due to improvement in soil different properties as result of compost. More shoot P contents mean more uptake of P in plant and more solubilization of P in soil. Results suggest that application of compost is very effective for mitigating effect of late sowing on growth of cotton and for improving characteristics of soil such as soil organic matter and others etc.

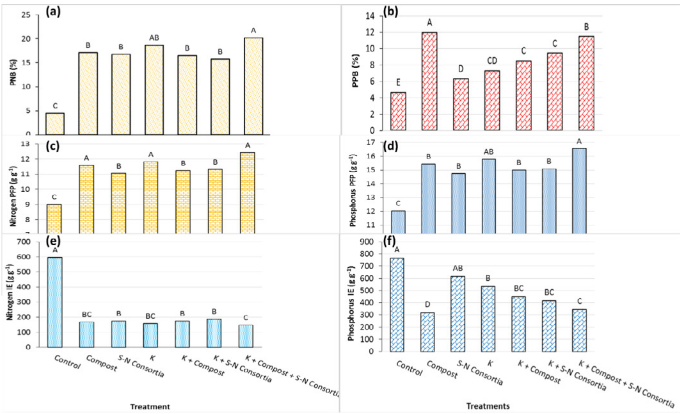

Figure 8: *Comparative effects of integrated compost, S-N Consortia and K application with conventional fertilizers on nutrient use efficiency. Bars with same capital letter(s) are at par (p <5%) according to HSD test.*

Figure 7c divulges the variations in shoot K contents due to compost, S-N consortia and K application. Least shoot K contents were found in control treatment whereas extreme shoot contents in treatment T_4 (foliar K). Treatment T_4 was followed by T_6 (compost + foliar K) and T_7 (compost + foliar K + S-N consortia) with 23-45% increase in shoot K contents over control treatment. Alone foliar K caused 5 to 55% more shoot K contents whereas foliar S-N consortia caused 4 to 15% more leaf N contents and alone compost resulted in 15% increase in shoot K contents over control Figure 7c. Combined application of compost, S-N consortia and K caused finally 45-65% more shoot K contents over control treatment, showing that combined application of treatment is better than alone application of compost, S-N consortia and K.

Nutrient use efficiency

Partial nitrogen balance: Variations in partial N balance (PNB) due to compost, S-N consortia and K application has been shown by Figure 8a that elucidates a clear-cut difference in PNB due to all the treatments. Minimum PNB was found in control treatment (T_1) whereas maximum PNB occurred in treatment T_7 (compost, S-N consortia + K) which was 252% more than PNB of control. Treatment T_7 was followed by T_4 (Foliar K). K based treatment caused 19-20% increase in PNB while compost based treatments resulted in 17-20% increase in PNB compared to control treatment. Compared to T_1, all treatments caused 4 to 20% increase in PNB, showing that application of compost, K and /or S-N consortia improve N recovery Figure 8a.

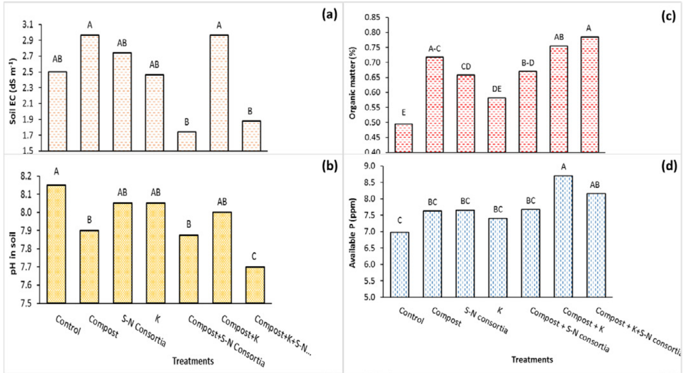

Figure 9: *Comparative effects of integrated compost, S-N Consortia and K application with conventional fertilizers on soil characteristics after harvesting of cotton crop. Bars with same capital letter(s) are at par (p <5%) according to HSD test.*

Partial phosphorus balance

Variations in partial P balance (PPB) due to compost, S-N consortia and K application have been shown by Figure 8b that elucidates a clear-cut difference in PNB due to all the treatments. Minimum PNB was found in control treatment (T_1) whereas maximum PPB occurred in treatment T_7 (compost, S-N consortia + K) which was 12% more than PPB of control. Treatment T_7 was followed by T_4 (Foliar K). K based treatment caused 7-11% increase in PPB while compost-based treatments resulted in 9-12% increase in PPB compared to control treatment. Compared to T_1, all treatments caused 5 to 12% increase in PPB, suggesting that application of compost, K and/or S-N consortia improve P recovery. Results suggest that application of compost is very effective for mitigating effect of late sowing on growth of cotton and for improving characteristics of soil such as soil organic matter and others etc. Figure 8d shows that P partial factor productivity was significantly improved due to treatments applied compared to control treatment.

Internal utilization efficiency of N fertilizers

Variations in internal utilization efficiency (IE) of N fertilizers due to compost, S-N consortia and K application have been shown by Figure 8e. Maximum IE of N fertilizers was found in control treatment (T_1) whereas least IE of N fertilizers occurred in treatment T_7 (compost, S-N consortia + K) which were 75% less than IE of N fertilizers in control Figure 8e. K based treatment caused a decline in IE of N fertilizers by

71-75% while compost based treatments resulted in 72-75% decrease in IE of N fertilizers compared to control treatment. Compared to T_1, there was 69 to 75% decrease in IE of N fertilizers due to application of compost, K and /or S-N consortia Figure 8e.

Internal utilization efficiency of P fertilizers
Variations in internal utilization efficiency (IE) of P fertilizers due to compost, S-N consortia and K application have been shown by Figure 8f. Maximum IE of P fertilizers was found in control treatment (T_1) whereas least IE of P fertilizers occurred in treatment T_7 (compost, S-N consortia + K) which were 55% less than IE of P fertilizers in control. K based treatment caused a decline in IE of P fertilizers by 20-55% while compost based treatments resulted in 72-75% decrease in IE of P fertilizers compared to control treatment. Compared to T_1, there was 20 to 55% decrease in IE of P fertilizers due to application of compost, K and /or S-N consortia (Figure 8f).

Improvements in soil characteristics
Application of compost significantly improved soil properties. Treatments consisting of compost significantly reduced soil pH (transit change) and soil EC which ultimately resulted in higher P availability to plant roots (Figure 9).

Conclusions and Recommendations

Results show that combined application of K + compost, compost + S-N consortia or K + compost + S-N consortia is better than alone application of K, compost or S-N consortia for mitigating heat stress on cotton sown in July (late-sown cotton). Results also suggest that farmers should use at least one of tested treatment for saving cotton under changing climatic conditions. Moreover, more research on this aspect will open new horizons for researcher and cotton growers under changing climatic conditions.

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Novelty Statement

This is first study to explore the application of potassium along with compost to reduce the heat stress on boll setting and lint quality under arid environment.

Author's Contribution

Muti Ul Hannan: Carried out the experiments, collected data and wrote the manuscript.
Wazir Ahmed: Contribute in planning the experiment and supervised.
Muhammad Naeem Akhtar, Muhammad Baqir Hussain and Khuram Mubeen: Assisted in laboratory. Helped in statistical analysis figures drawing and revision of the manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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