INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
19–0065/2019/22–1–115–121
DOI: 10.17957/IJAB/15.1040
http://www.fspublishers.org

Full Length Article

Combined Foliar Applied Nitrogen, Potassium and Magnesium Improved Yield, Fiber Quality and Water Use Efficiency of Cotton under Water Limited Environment

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Abstract

Cotton crop is highly sensitive to water stress; however wise nutrient management might be useful to improve seed cotton yield and fiber quality of cotton under water stress conditions. In this two-year study, the influence of combined foliar application of nitrogen (N), potassium (K) and magnesium (Mg) was observed on seed cotton yield, fiber quality and water use efficiency. The experiment consisted of two water levels *viz*., i) no water stress (well-watered; 634 mm) and ii) water stress (deficit water; 482 mm) and five foliar treatments including i) control (no nutrient foliar spray), ii) FS_1= K (2.5 g L^{-1} water) + Mg (1 g L^{-1} water) + N (11.5 g L^{-1} water); iii) FS_2= Mg (1 g L^{-1} water) + K (2.5 g L^{-1} water); iv) FS_3= K (2.5 g L^{-1} water) + N (11.5 g L^{-1} water) and v) FS_4= Mg (1 g L^{-1} water) + N (11.5 g L^{-1} water). The water stress was imposed by skipping two irrigations (at vegetative and flowering stage) in cotton crop. Each foliar application was made in two splits at 50 and 70 days after sowing. Water stress significantly decreased the seed cotton yield and fiber quality of cotton. However, combined foliar application of N, K and Mg improved the seed cotton yield, fiber quality, leaf N, K and Mg concentration and water use efficiency of cotton. The improvement in fiber quality was visible through improvement in fiber strength, micronaire, staple length and fiber uniformity index. The highest seed cotton yield, fiber quality and water use efficiency was recorded with combined foliar application of Mg, K and N under well-watered and water stress conditions. © 2019 Friends Science Publishers

Keywords: Cotton; Water stress; Nitrogen; Magnesium; Potassium; Fiber quality; Water use efficiency

Introduction

Cotton (*Gossypium hirsutum* L.) is an important fiber and oilseed crop which has a key role in boosting the economy of many countries across the globe, including Pakistan (Ali *et al*., 2019). Cotton is sensitive to water stress and, its productivity and fiber quality are threatened due to increasing water scarcity across the globe (Haim *et al.,* 2008; Dağdelen *et al.,* 2009).

In this scenario, exogenous application of plant nutrients (N, K and Mg) might be useful to improve the seed cotton yield and fiber quality of cotton under abiotic stresses including water stress. Nitrogen has key role in the synthesis of protein, cell division and chlorophyll synthesis (Tajer, 2016) and its foliar application has been reported to improve cotton production under salinity stress (Chen *et al.,* 2010). The role of K in improving the performance of field crops under abiotic and biotic stresses is well known (Cakmak, 2005; Wang *et al.,* 2013; Hussain *et al*., 2018). Indeed, use of K in cotton decreases the severity and incidence of diseases, improves the water use efficiency (WUE) and fiber quality by maintaining a surplus water pressure within the boll (Stewart, 2005). Potassium application in cotton is also believed to extend the absorption of N which causes vigorous vegetative growth and seed cotton yield (Ali *et al.,* 2007). In a study, use of K in cotton enhanced the metabolic activity and improved the staple length, tensile strength, fiber micronaire and decreased the amount of damaged fiber (Dong *et al.,* 2005). Similarly, Mg is the component of enzymes in ATP formation and helps in the preparation of plant metabolites (Marschner, 2012; Igamberdiev and Kleezkowski, 2015), and assimilation of proteins and carbohydrates (Cakmak *et al.,* 2008). In a study, Sankaranarayanan *et al.* (2010) reported that 0.5% solution of Mg alone or in combination with zinc, iron and boron improved the cotton performance as compared to control treatment.

The soil application of macro- and micronutrients (including K) is most common way of improving the soil fertility (Ali *et al.,* 2007). However, large doses of fertilizers are needed for soil application (Mesbah, 2009). The loss of soil applied nitrogenous fertilizers is high in arid regions due

To cite this paper: Ali, H., M.S. Tahir, S. Hussain, R.N. Shabbir, A. Areeb and A. Sher, 2019. Combined foliar applied nitrogen, potassium and magnesium improved yield, fiber quality and water use efficiency of cotton under water limited environment. *Intl. J. Agric. Biol.*, 22: 115–121

to high temperature. Thus, to reduce the potential losses of soil applied fertilizers, the alternate methods of application of fertilizers might be useful. In this scenario, foliar application of plant nutrients might be a viable option (Fageria *et al.,* 2009; Haider *et al*., 2018). Improvement in yields of wheat (*Triticum aestivum* L.) and cotton has been reported due to foliar application of urea and diammonium phosphate (Raju *et al*., 2008; Parvez *et al.,* 2009). Sharma and Sundar (2007) also reported an improvement in fiber characteristics of cotton with foliar spray of K_2O at boll formation stage. In another study, foliar spray of Mg on cotton produced greater number of bolls, higher boll weight and seed cotton yield (Rajakumar and Gurumurthy, 2008).

The effects of combined foliar application of N, K and Mg under water stress in cotton has not been exploited in past. For this study, we hypothesized that combined foliar application of N, K and Mg may improve morphological features, yield parameters and seed cotton yield under water stress conditions. The specific objective of this study was to check the influence of combined foliar application of N, K and Mg on fiber quality and WUE of cotton crop grown under water stress conditions.

Materials and Methods

Site Soil and Climate

This two year experiment was conducted at the farm area of the Agronomic Section, Central Cotton Research Institute, Multan (71.43°E, 30.2°N and 122 masl.), Pakistan during the years 2013 and 2014. The experimental station is characterized by a hot climate and low annual rainfall with a silt loam soil. Weather data is given in Table 1 and the soil properties are given in Table 2.

Seedbed Preparation, Experimental Design and Crop Husbandry

Prior to layout of the experiment, a pre-sowing irrigation (10 cm) was applied to the field to bring the soil at optimal soil moisture for facilitating the seed germination. When, the soil reached at workable soil moisture, it was cultivated twice with tractor mounted cultivator followed by two plankings. The ridges were made with help of a tractor mounted ridger. The crop was sown on 75 cm spaced ridges on May 29 and 31 during the years 2013 and 2014, respectively. The cotton seeds were sown manually keeping a distance of 20 cm between plants. Nitrogen and phosphorus (P) in the form of urea and diammonium phosphate (at the rate of 150 and 120 kg ha^{-1}, respectively) were applied. All the P fertilizer was applied at the time of seedbed preparation while the N was applied in three equal splits (at sowing and at 1st and 2nd irrigation).

The experiment was laid out in randomized complete block design in split-plot arrangement keeping two water levels *viz*., i) no water stress (well-watered; 634 mm) and ii) water stress (deficit water; 482 mm) in main plots and foliar applied nutrient treatments in sub-plots having net plot size specified with dimensions of 6.0 m × 9.0 m.

The foliar applied nutrient treatments consisted of i) control= no nutrient foliar spray, ii) FS_1= K (2.5 g L^{-1} water) + Mg (1 g L^{-1} water) + N (11.5 g L^{-1} water); iii) FS_2= Mg (1 g L^{-1} water) + K (2.5 g L^{-1} water); iv) FS_3= K (2.5 g L^{-1} water) + N (11.5 g L^{-1} water); and v) FS_4= Mg (1 g L^{-1} water) + N (11.5 g L^{-1} water). Potassium sulphate (50% K_2O), magnesium sulphate (20.19% Mg) and urea (46% N) were used as sources of potassium, magnesium and nitrogen, respectively.

For the preparation of foliar spray solutions in different treatment combinations, 5 g of potassium sulphate, 5 g of magnesium sulphate and 25 g of urea were dissolved per liter of solution as per treatment. A surfactant *i.e*., 0.1% Tween 20 was also added in solution to ensure proper mixing of each nutrient in solution. The foliar spray was performed in the morning (08:00 to 10:00 a.m.) on sunny days and repeated after 50 and 70 DAS during the years 2013 and 2014. Each foliar application was made in two splits at 50 and 70 days after sowing.

In total, eight irrigations were applied to well-watered treatment to fulfill the water requirement of cotton crop during both years. For water stress treatment, six irrigations were applied by skipping two irrigations (at vegetative and flowering stage). Cut throat flumes were installed at water channel to apply the measured amount of water to normal and water stress plots. In the normal irrigation plan, during the year 2013, the plots under normal irrigation received 466 mm of water through irrigation water and 168 mm through rainfall (total water of 634 mm). The plots under water stress treatment received a total of 482 mm water (314 mm through irrigation + 168 mm through rainfall) during the year 2013. During the year 2014, the plots under normal irrigation treatment received 543 mm of water through irrigational water and 91 mm of water through rainfall (total water 634 mm). The plots under water stress treatment received a total of 482 mm water (391 mm through irrigation + 91 mm through rainfall). Weeds were manually controlled in experimental plots. The insect pests were controlled using the recommended insecticides as per recommendation of the Government of Punjab, Pakistan. The crop was harvested on December 15 in 2013 and 2014, respectively.

Data Recording

Morphological and yield parameters: The leaf area index was calculated as the ratio of leaf area to land area (Watson, 1947). The chlorophyll contents were recorded at maturity with the help of a spade meter as detailed in Ling *et al.* (2011). Five healthy plants were taken randomly at maturity to record the number of bolls per plant. Three samples of 100 bolls were taken from each plot to record the 100-boll weight. The seed cotton was picked from each boll after boll

Table 1: Daily minimum and maximum temperature, relative humidity, wind speed, rainfall and solar radiation during 2013 and 2014

Months	Temperature (°C)				Relative humidity (%)				Wind speed (km h^{-1})		Sunshine hours (h)		Rainfall (mm)	
	Max.	Min.	Max.	Min.	8 AM	5 PM	8 AM	5 PM						
	2013		2014		2013		2014		2013	2014	2013	2014	2013	2014
Jun	38.8	29.2	39.9	30.5	71.5	64.2	62.1	42.4	7.9	7.8	7.8	7.6	50.7	1.4
July	38.1	29.8	36.8	29.4	71.8	57.2	70.6	51.5	6.6	7.4	7.9	6.6	40.0	51.6
August	35.2	27.9	35.7	28.4	77.1	67.3	80.9	61.5	5.5	6.7	7.1	8.8	74.2	16.5
September	35.2	25.4	34.1	25.6	79.5	63.8	85.4	65.5	4.9	4.2	8.7	7.4	0.0	4.3
October	35.2	24.4	31.5	20.5	77.9	64.7	83.1	63.3	3.4	2.7	7.8	6.1	3.3	17.7
November	26.9	13.1	26.3	12.0	84.1	74.6	86.0	68.0	2.6	2.1	5.7	5.0	0.0	0.0
December	20.4	9.3	17.8	6.9	89.7	75.0	93.6	74.9	3.1	2.6	4.9	3.8	0.0	0.0

Table 2: Soil properties of the experimental site during 2013 and 2014

Soil property		2013		2014	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm
pH of soil (1:1)		8.14	8.15	8.14	8.17
EC_e (dS m^{-1})		1.61	1.68	1.65	1.72
Sodium absorption ratio		2.44	1.78	2.46	1.76
Soil organic matter (%)		0.84	0.81	0.86	0.82
Total nitrogen (%)		0.091	0.061	0.092	0.062
Available phosphorous (mg kg^{-1})		13.5	11.2	13.6	11.6
Exchangeable potassium (mg kg^{-1})		133	135	138	136
Mg^{2+} ions (mg kg^{-1})		11	13	11.2	13.2
Soil separates	Sand (%)	15	17	16	13
	Silt (%)	53	58	57	61
	Clay (%)	27	25	29	26
Texture class		Silt loam	Silt loam	Silt loam	Silt loam

opening at regular intervals. The seed cotton yield was calculated by adding the seed cotton from all pickings and was expressed in kg ha^{-1}.

Fiber Quality Parameters and Water Use Efficiency

For the measurement of fiber quality parameters, the samples were prepared accordingly. For this, the cotton seeds were ginned in electrically powered ginning machines to separate lint from seed followed by cleaning of those samples. Each sample was conditioned at optimum temperature of 20±2˚C with 65 ± 2% relative humidity level in air conditioned chamber. The humidity level was tested by a humidifier (HIV-900) at the humidity level of 8.5%. Uniformity index was taken following the USDA classification method (Taylor, 1998). For the measurement of micronaire value (μg $inch^{-1}$), the prepared sample was passed through X-ray to record the structural arrangement of the lint. The fiber strength was tested by forcing the sample through mortar and the data was recorded on RD% (reflectance degree) and degree of yellowness of fiber for the determination of fiber strength. Staple length was estimated following the method of Moore (1996).

The WUE (kg ha^{-1} mm^{-1}) was calculated following Viets (1962) by the given formula:

$$\text{Water use effciency} = \frac{\text{Seed cotton yield (kg/ha)}}{\text{Water applied [irrigation (mm) + rainfall mm)]}}$$

Leaf Nutrient Concentration

Magnesium concentration in leaves was measured by titration method in which the measured volume of the leaf sample was titrated with EDTA having eriochrome black-T indicator using ammonium chloride and ammonium hydroxide as buffer. The leaf potassium was determined by using Sherwood Flame Photometer 410 following Helmke and Sparks (1996). Leaf N concentration was estimated using the Kjeldahl nitrogen method (EPA method 351.2) as detailed in Jones and Case (1991).

Statistical Analysis

Data collected from the field trials was subjected to statistical analysis using 'Statistix 8.1' computer software. The analysis of variance was performed to test the significance of treatment means. If the means were found significant, they were separated by using least significant test at 5% probability level (Steel *et al.*, 1997). The Microsoft excel was used to draw the graphs and insert the standard errors on bars.

Results

Morphological/yield Parameters and Seed Cotton Yield

Water stress significantly decreased the number of bolls per plant, 100- boll weight, chlorophyll contents and seed cotton yield of cotton during both years of study (Table 3, 4 and 5). However, foliar application of K, Mg and N in different combinations significantly improved the bolls per plant, 100-boll weight, chlorophyll contents and seed cotton yield of cotton during both years. The interaction of foliar applied

Table 3: Influence of foliar applied nitrogen, potassium and magnesium on yield related traits of cotton under normal and water stress conditions

Treatments	Number of bolls per plant				100-boll weight (g)				Seed cotton yield (kg ha^{-1})				Lint percentage (%)			
	2013		2014		2013		2014		2013		2014		2013		2014	
	Normal	Water Stress	Normal	Water Stress	Normal	Water Stress	Normal	Water Stress	Normal	Water Stress	Normal	Water Stress	Normal	Water Stress	Normal	Water Stress
C	32.75cd	27.00de	33.25cd	28.0de	231ef	202g	239b	202d	1235e	1160e	1386f	1164h	37.18de	36.55e	37.38c	36.28d
FS_1	44.00a	39.50ab	46.75a	35.0bcd	282a	239cde	276a	245b	1890a	1693b	2114a	1719c	43.48a	40.75bc	43.70a	41.80b
FS_2	1.25ab	37.00bc	40.75ab	32.25de	267b	232def	275a	237bc	1657b	1377d	1867b	1279g	41.13bc	40.97bc	41.80b	41.03b
FS_3	32.50cd	24.00e	33.0cde	25.75e	247c	221f	245b	226c	1439cd	1397cd	1497e	1397ef	37.83d	37.10de	37.20c	37.40c
FS_4	40.25ab	35.50bc	40.25abc	35.25bcd	285a	244cd	287a	242b	1898a	1497c	1956b	1582d	41.35b	40.35c	41.38b	41.20b
LSD ($p \leq 0.05$)	6.33		7.32		11.93		12.92		116.5		107.3		0.91		0.90	

C= control (no nutrient foliar spray); FS_1= K (2.5 g L^{-1} water) + Mg (1 g L^{-1} water) + N (11.5 g L^{-1} water); FS_2= Mg (1 g L^{-1} water) + K (2.5 g L^{-1} water); FS_3= K (2.5 g L^{-1} water) + N (11.5 g L^{-1} water); FS_4= Mg (1 g L^{-1} water) + N (11.5 g L^{-1} water)

Table 4: Influence of foliar applied nitrogen, potassium and magnesium on fiber characteristics of cotton under normal and water stress conditions

Treatments	Fiber strength (G/Tx)		Staple length (cm)		Uniformity Index		Micronaire (μg inch^{-1})	
	2013	2014	2013	2014	2013	2014	2013	2014
Water levels								
Normal	27.67 A	28.04 A	27.6A	27.5	80.6	80.5	4.285	4.370 A
Water stress	27.09 B	27.22 B	26.9B	26.7	80.6	80.4	4.180	4.180 B
LSD ($p \leq 0.05$)	0.34	0.41	0.11	NS	NS	NS	NS	0.1233
Foliar spray of nutrients								
Control	26.45 D	26.36 D	26.3C	25.5D	78.75 C	78.31D	4.113 C	4.125 C
FS_1	28.59 A	28.90 A	28.4A	28.2A	82.0A	82.2A	4.538 A	4.575 A
FS_2	27.98 B	27.95 B	27.2B	27.2B	81.7AB	80.7B	4.150 BC	4.300 B
FS_3	26.66 D	26.95 C	26.7C	26.4C	79.4C	80.0C	4.100 C	4.112 C
FS_4	27.23 C	27.98 B	27.6B	27.7A	81.2B	81.1B	4.263 B	4.263 BC
LSD ($p \leq 0.05$)	0.4002	0.3785	0.52	0.65	0.77	0.60	0.1376	0.1555
Interaction	**	**	NS	NS	NS	NS	NS	*

C= control (no nutrient foliar spray); FS_1= K (2.5 g L^{-1} water) + Mg (1 g L^{-1} water) + N (11.5 g L^{-1} water); FS_2= Mg (1 g L^{-1} water) + K (2.5 g L^{-1} water); FS_3= K (2.5 g L^{-1} water) + N (11.5 g L^{-1} water); FS_4= Mg (1 g L^{-1} water) + N (11.5 g L^{-1} water)

Table 5: Influence of foliar applied nitrogen, potassium and magnesium on chlorophyll contents, leaf nitrogen, leaf potassium and leaf magnesium of cotton under normal and water stress conditions

Treatments	Chlorophyll contents		Leaf nitrogen (ppm)		Leaf potassium (ppm)		Leaf magnesium (ppm)	
	2013	2014	2013	2014	2013	2014	2013	2014
Normal	38.8A	38.4A	4.6	3.7A	1.3A	1.3A	381.6A	365.8A
Water stress	32.4B	34.6B	4.5	3.0B	1.2B	1.2B	315.7B	323.1B
LSD ($p \leq 0.05$)	1.94	2.03	NS	0.32	0.1	0.09	22.64	5.52
Control	23.39B	23.1C	1.3C	1.5D	0.6C	0.6C	281.7D	293.4D
FS_1	38.1A	38.0B	6.2B	4.9A	1.6B	1.4A	348.6 C	326.5C
FS_2	37.9A	38.2B	1.6C	1.8C	1.7A	1.4A	401.4B	362.1B
FS_3	37.8A	37.8 B	6.9A	4.4B	1.7A	1.5A	265.1D	295.1D
FS_4	40.9A	46.3 A	6.8A	4.1B	0.7C	1.1B	446.4A	445.1A
LSD ($p \leq 0.05$)	5.39	6.22	0.30	0.26	0.09	0.07	16.95	10.86
Interaction	NS	NS	NS	***	NS	**	NS	**

C= control (no nutrient foliar spray); FS_1= K (2.5 g L^{-1} water) + Mg (1 g L^{-1} water) + N (11.5 g L^{-1} water); FS_2= Mg (1 g L^{-1} water) + K (2.5 g L^{-1} water); FS_3= K (2.5 g L^{-1} water) + N (11.5 g L^{-1} water); FS_4= Mg (1 g L^{-1} water) + N (11.5 g L^{-1} water)

nutrients with water levels was also significant for bolls per plant, 100-boll weight and seed cotton yield during both years (Table 3). During both years, the highest number of bolls per plant was recorded with combined foliar application of K and Mg with N under normal and water stress conditions. However, number of bolls per plant was statistically similar with the combined foliar application of K with Mg and combined foliar application of Mg with N under normal conditions.

The combined foliar application of Mg with N was as effective for improvement in number of bolls per plant as the combined application of K and Mg with N under water stress conditions during the second year (Table 3). Under normal conditions, the 100-boll weight was the highest for combined foliar application of Mg with N and was statistically similar with combined foliar application of K and Mg with N during both years and with combined foliar application of K with Mg during 2014. A similar type of trend was observed for improvement in 100-boll weight of cotton due to foliar application of nutrients under water stress conditions during both years (Table 3).

Under normal condition, the highest seed cotton yield was recorded with the combined foliar application of Mg with N and was statistically similar with combined foliar application of K and Mg with N during 2013 (Table 3). During 2014, the highest seed cotton yield was recorded with combined foliar application of K and Mg with N under normal conditions (Table 3). During both years, combined foliar application of K and Mg with N was most beneficial for improvement in seed cotton yield under water stress conditions (Table 3). During first year, the foliar application of K and N with Mg in all combination was equally effective for improvement in chlorophyll contents than control. However, combined foliar application of Mg with N produced significantly higher chlorophyll contents than other treatments during second year of experimentation (Table 5).

Water stress caused a significant decrease in the leaf area index; nonetheless, foliar applied nutrients in different combinations significantly improved the leaf area index under normal and water stress conditions. Under, a normal condition, the highest leaf area index was recorded with combined foliar application of K and Mg with N during both years. During 2013, the combined foliar application of K and Mg with N and individual foliar application of either K or Mg with N was equally effective for improvement in leaf area index under water stress conditions. However, during the second year, combined foliar application of K with Mg and individual application of either K or Mg with N was equally effective for improvement in leaf area index under water stress conditions (Fig. 1).

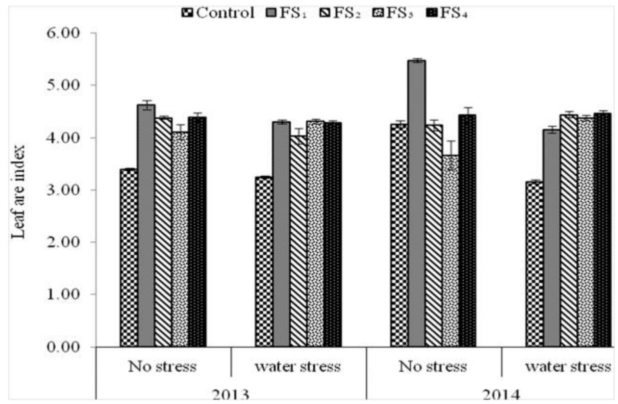

Fig. 1: Influence of foliar applied nitrogen, potassium and magnesium on leaf area index of cotton under normal and water stress conditions; FS_1= K (2.5 g L^{-1} water) + Mg (1 g L^{-1} water) + N (11.5 g L^{-1} water); FS_2= Mg (1 g L^{-1} water) + K (2.5 g L^{-1} water); FS_3= K (2.5 g L^{-1} water) + N (11.5 g L^{-1} water); FS_4= Mg (1 g L^{-1} water) + N (11.5 g L^{-1} water)

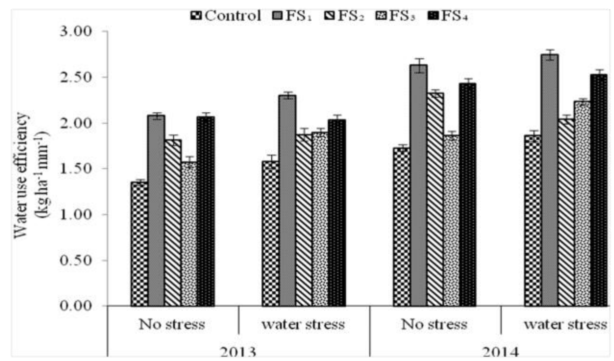

Fig. 2: Influence of foliar applied nitrogen, potassium and magnesium on water use efficiency (kg $ha^{-1}mm^{-1}$) of cotton under normal and water stress conditions; FS_1= K (2.5 g L^{-1} water) + Mg (1 g L^{-1} water) + N (11.5 g L^{-1} water); FS_2= Mg (1 g L^{-1} water) + K (2.5 g L^{-1} water); FS_3= K (2.5 g L^{-1} water) + N (11.5 g L^{-1} water); FS_4= Mg (1 g L^{-1} water) + N (11.5 g L^{-1} water)

Fiber Quality

Water stress significantly decreased the lint percentage, fiber strength and micronaire during both years; and the staple length of cotton during first year of experimentation (Table 4). However, combined foliar application of K and Mg with N in different combination significantly improved the lint percentage, fiber strength, micronaire, staple length and the uniformity index of cotton, under normal and water stress conditions during both years (Table 4). During both years, the highest lint percentage and fiber strength was recorded with combined foliar application of K and Mg with N under normal and water stress conditions and was statistically similar with combined foliar application of K with Mg; or with combined foliar application of Mg with N under water stress conditions for lint percentage during both years (Table 3). During both years, the highest micronaire was recorded with combined foliar application of Mg with N under normal and water stress conditions (Table 4). During both years the highest staple length and uniformity index was recorded with combined foliar application of K and Mg with N and was statistically similar with combined foliar application of Mg with N during second year (Table 4).

Leaf Nutrient Concentration and Water Use Efficiency

Combined foliar application of K and Mg with N in different combinations significantly improved the leaf N, K and Mg during both years. The highest leaf N was recorded with individual application of K or Mg with N during 2013 and with combined foliar application of K and Mg with N in 2014 (Table 5). Combined foliar application of K with N and combined foliar application of Mg with K resulted in significantly higher leaf K concentration in cotton during both years and was statistically similar with the combined foliar application of K and Mg with N during the second year of experimentation (Table 5). Leaf Mg concentration was significantly higher with the combined foliar application of K and Mg with N during both years (Table 5). During both years, the WUE was significantly higher with combined foliar application of K and Mg with N and was followed by combined foliar application of Mg with N under normal and water stress conditions (Fig. 2).

Discussion

This study indicated that water stress significantly decreased the morphological (leaf area index), yield parameters (number of bolls per plant, 100-boll weight) and chlorophyll contents of cotton which resulted in lower seed cotton yield. Water stress also decreased the fiber quality, which was visible through reduction in the lint percentage, fiber strength, micronaire and staple length of cotton. This reduction in the seed cotton yield due to water stress might be attributed to the reduction in leaf area (Fig. 2), owing to a decrease in leaf size and relative water contents (Lawlor and Cornic, 2002; Pettigrew, 2004), which might have affected leaf photosynthesis in cotton (Lawlor and Cornic, 2002). Some earlier studies have also reported that water stress in cotton reduces the photosynthesis, due to several stomatal and non-stomatal limitations (Faver *et al.*, 1996; Lacape *et al.*, 1998; Leidi *et al.*, 1999), decreases the quantum efficiency of photosystem II (Ennahli and Earl, 2005; Inamullah and Isoda, 2005; Kitao and Lei, 2007) and finally reduces the flower production, boll formation, enhances the boll abortion (Pettigrew, 2004), thus affecting the seed cotton yield as was observed in this study. Reduction in cotton growth due to water stress also resulted in lower fiber quality in cotton. Several other studies have also reported that water stress negatively affects the cotton yield and fiber quality grown under diverse environmental conditions (Gwathmey *et al.*, 2011; Lokhande and Reddy, 2014; Wang *et al.*, 2016).

However, foliar sprays of K, Mg and N in variable combinations improved the leaf area index and stay green under water stress which resulted in higher boll formation, increased boll weight and finally the highest seed cotton and improved fiber quality as compared with the control treatment. Indeed, N and K provide the raw materials for the synthesis of vegetative and reproductive growth parameters; while Mg is the component of chlorophyll which increases the photosynthetic activity with increase in assimilation of photosynthates. Magnesium is the component of enzymes in ATP formation and helps in the preparation of plant metabolites (Marschner, 2012; Igamberdiev and Kleezkowski, 2015). Magnesium also plays very important physiological functions in the plants like assimilation of proteins and carbohydrates by translocating the materials from leaves to roots and fruit through partitioning (Cakmak *et al.*, 2008). In an earlier study on cotton, 0.5% solution of $MgSO_4$ alone or in combination with zinc, iron and boron improved the vegetative and reproductive growth parameters as compared to control treatment (Sankaranarayanan *et al.*, 2010). In another study, the lint and seed cotton yield were improved by foliar application of K, zinc and P (Sawan *et al.*, 2008).

Likewise, an improvement in the seed cotton yield and quality due to foliar application of K might be attributed to the involvement of K in several metabolic processes of crop plants. For example, use of K in cotton decreases the severity and incidence of diseases, improves the efficiency of water use, and fiber quality by maintaining a surplus water pressure within the boll (Stewart, 2005). On the other hand, shortage of K in cotton may decrease the fiber quality by exposing the plants to water stress and diseases (Stewart, 2005). Moreover, the improvement in cotton performance due to foliar applied K under water stress might be attributed to the increased photosynthetic rate owing to role of K in carbon dioxide fixation and cell turgor control (Marschner, 1995). Potassium application in cotton is also believed to extend the absorption of N which causes vigorous vegetative growth (Ali *et al.*, 2007) and ultimately improve the yield as was observed in this study when K was applied in combination with N. In a previous study, use of K in cotton enhanced the metabolic activity and improved the staple length, tensile strength, fiber micronaire, and decreased the amount of damaged fiber (Dong *et al.*, 2005).

Foliar application of N in the form of urea was also useful for improvement in seed cotton yield and quality in combination with Mg and K. Earlier, N application has been reported to improve the cotton performance under abiotic stresses. For example, N application at low salinity level (12.5 dS m^{-1}) improved the uptake of N and performance of cotton crop (Chen *et al.*, 2010) which might be attributed to involvement of N in the synthesis of protein, cell division and chlorophyll synthesis (Tajer, 2016). Improvement in WUE due to foliar applied N, K and Mg was due to improved seed cotton yield in this study (Table 3).

Conclusion

Foliar application of Mg in combination with K and N improved the seed cotton yield, fiber quality, leaf N, K and Mg concentrations and WUE of cotton. The improvement in fiber quality was also visible through improvement in fiber strength, micronaire, staple length and fiber uniformity index owing to combined foliar application of Mg in combination with K and N. Thus, the combined foliar application of Mg, K and N might be a viable option to improve seed cotton yield, fiber quality and WUE under water stress conditions.

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[Received 14 Jan 2018; Accepted 19 Feb 2019; Published (online) 26 Apr 2019]