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RESEARCH ARTICLE

EFFECTS OF DROUGHT, FERTILIZER AND MUCLH ON MAIZE BIOMASS AND SOME SOIL PROPERTIES

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ABSTRACT

A decrease of water resources around the globe in irrigated agriculture has resulted in a steep decline in irrigation water availability. Therefore, management options for efficient use of available irrigation water are inevitable. In addition to that, the judicious use of combinations of organic and inorganic resources is a feasible approach to overcome soil fertility constraints. Hence, effects of drought, fertilizer and mulch on maize biomass and some soil properties were examined in a green house. The objective was to determine measures which will enhance resistance to drought and increase maize biomass with improved soil conservation. Twelve treatments were considered by varying irrigation, mulch, and fertilizer. Experimental results revealed that: (i) Mulch application increased Water Used Efficiency (WUE) by 30.18% and 34.80% under full irrigation in 2005 and 2006. (ii) Mulch decreased under ground biomass by 21, 30.20 and 2.4% under full irrigation, mild, and serious stress. (iii) The use of fertilizer alone increases underground biomass by 16.98 and 32.19% in 2005 and 2006. (iv) Mulch application reduced soil bulk density by 1.53% under mild stress treatment.

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INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereals for both human and animal consumption. It is planted for grain and forage. In term of global production, maize is the third most important food crop after rice and wheat (USDA, 2011). It is now the most widely produced cereal crop with an overall production of approximately 1006.18 million tones (FAO-AMIS, 2016). Maize is currently produced on nearly 184 million hectares in 125 developing countries (FAO, 2014). Drought is considered as one of the most important factors that limit plant production in arid and semi-arid zones (Hussein *et al.,* 2011), where such areas are subjected to a wide range of climate variations as well as climate changes.

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Under such conditions, lower yield and lower water use efficiency take place especially under the instability of water amounts from year to year (Oweiss *et al.,* 2000). Maize is highly sensitive to drought, especially two weeks prior and post silking (Tollenaar and Lee, 2011). Adequate water and nutrient supply are important factors affecting optimal plant growth and successful crop production. Moreover, application of irrigation deficit alone does not gives positive results regarding crop production or soil quality and under such critical condition, management methods that decrease requirements for agricultural chemicals are needed in order to avoid adverse environment impacts (Bilalis *et al.,* 2009). The use of manure and mulching are two of the basic cultivation techniques of organic agriculture (Ethimiadou *et al.,* 2009). However, emerging evidence indicated that integrated nutrient management involving the judicious use of combinations of organic and inorganic resources is a feasible approach to overcome soil fertility constraints (Abedi *et al.,* 2010). Several studies have reported that Farm yard manure plus inorganic N applications in irrigated systems resulted in reduced bulk density, higher soil organic matter and hydraulic conductivity and improved soil structure and microbial communities (Bhattacharyya *et al*., 2007). Kaur *et al*., (2008) stated that a judicious combination of organic amendments and inorganic fertilizers is widely recognized strategy of integrated nutrient management to sustain agronomic productivity and improve soil fertility. Addition of organic materials of various origins to soil has been one of the most common practices to improve soil physical properties (Celik *et al*., 2004). Information about the interaction of drought fertilizer and mulch on maize biomass and soil properties under controlled conditions are scanty. Thus, the objectives of the study are:

- To determine the effects of drought, fertilizer and mulch on biomass, root to shoot ratio and water used efficiency of maize.
- To investigate the impacts of drought, fertilizer and mulch on soil properties.
- To examine the interactive effects of drought, fertilizer and mulch on biomass, root to shoot ratio and water used efficiency of maize and on soil properties.

MATERIALS AND METHODS

Experimental site: A green house experiment was carried out in 2005 and 2006 at the experimental farm of Agricultural Engineering Department, Hohai University, Nanjing, China ($31^0$95' N latitude and $118^0$83' E longitude). The climate is sub humid with an average annual rainfall of 1106 millimeter (mm). The soil of the experimental site is clay loam with 33.81% clay, 65% silt, 0.97% sand and a pH (1:2.5 soil: water) of 7.96. The organic matter content is 12.26mg kg^{-1}. The available nitrogen and available phosphorus are 47.4 and 10.13 mg kg^{-1} respectively. Nanjing Agricultural University Maize Variety 108 (Nongda 108) was used as a test crop. Nongda 108 was planted on June 19 and harvested on October 17 in 2005 and 2006.

Experimental details

The experimental design is a Randomized Complete Block Design with three replications. Twelve treatments were considered (Table 1). Each plot is 2.25m x 1.5 m. The seeds were sown at 5 cm depth and 40 x30 cm row spacing in plots. Five (5) seeds were planted in each hole and thinned to 1 after two weeks of emergence. So, each plot has 30 plants. Prior to sowing; urea was applied in rows 10 cm deep at the rate of 375 kg ha^{-1} for all plots. The first weeding was carried out at two weeks after planting. Rice residues were applied as mulch at the rate of 6 t ha^{-1}, 15 days after maize emergence to some plots. Mulch residues have been cut into pieces of nearly 5 cm prior to application. Plant parameters measurements started 3 weeks after plant emergence, which is when 40% of plants have 5 leaves. Plants were exposed to stress at seedling stage at 31 Days after planting (DAP). At the end of stress time, that is at 45 DAP, fertilizer urea ($CO(NH_2)_2$) at the rate of 240 kg ha^{-1} was applied to some plots. Harvesting was done on October 17th each year. For analysis, shoot and root biomass were taken, oven dried for 72 hours at 65 ^{o} C and thereafter weighed. Soil water content at 0-60 cm depth was measured with neutron probe meter (MPM-160B) at intervals of 7-10 days. The water absorbed from the soil for a given interval was taken as the decrease in soil water in 0-60 cm depth interval. Evapotranspiration for the same interval was considered to be the total amount of water absorbed from the soil plus irrigated water. Composite soil samples at 0-20 cm depths were taken randomly with auger from each plot in november 2005 and 2006 (after harvesting maize) and june 2006 after harvesting wheat. The collected samples were air dried, crushed, sieved through a 2 mm sieve and analyzed for pH (water), available nitrogen and bulk density.

Statistical analyses: All statistical analyses were performed using General Linear Models (GLM) procedures in SPSS, Version 20 package. Three way ANOVA analyses were carried out over all twelve treatments to test explicitly the effects of deficit irrigation, mulch and fertilizer on maize biomass, root to shoot ratio and water used efficiency and on soil properties. Water application, mulch and fertilizer were treated as fixed factors in all the analyses while maize biomass, root to shoot ratio, water used efficiency, soil pH, available nitrogen and soil bulk density as dependent variables.

RESULTS AND DISCUSSION

Water supply: The water supplies in millimeters for different treatments during the growth of maize are given in Table 2. Mulch application reduced the amount of water needed to grow maize by 11.63%, 6.36% and 6.10% under full irrigation, mild and severe stress treatments in 2005. In 2006, the decrease was 13.71%, 4.95% and 7.47% for full irrigation, mild and severe stress respectively. According to Chakraborty *et al.*, 2008, mulching reduces unproductive evaporation from the soil surface, so more water is available for transpiration, which is of benefit in water limited conditions and plant water status is maintained. Our results are in line with those of Liu *et al.*, 2002, who reported that mulch increases the soil moisture and nutrients availability to plant roots, in turn, leading to higher grain yield.

Biomass, root to shoot ratio and water use efficiency of maize: Biomass values and ratios are presented in Table 3. Both fertilizer and water did not have any significant effect on underground biomass. However, mulch application significantly ($p<0.05$) affect aboveground biomass in 2005 and 2006. In 2005, mulch application increases above ground biomass by 14.10% under full irrigation (Table 3). While for underground biomass, a decrease of 21%, 30.20% and 2.47% were observed for full irrigation, mild and serious stress. These results corroborate with the findings of Xu *et al.* (2015) who reported that plastic mulching improves the accumulation of dry matter, leading to a significantly greater final biomass and improvement of grain yield of maize by 15 to 26% in the dry years. Shen *et al.* (2012) found that, under rain fed conditions in northern China, straw mulching could significantly enhanced the grain yield of summer maize. The application of mulch leads to improve net return of crops through maximizing yield and water productivity (Dekhordi *et al.,* 2016; Singh *et al.,* 2016). The use of fertilizer alone increases aboveground biomass in non mulch treatment under full irrigation by 12.22 and 20.03% in 2005 and 2006 respectively. For underground biomass, the increases were 16.98 and 32.19% in 2005 and 2006. Similar results were also revealed by Jiang *et al.* (2012). Ahadiyat *et al.* (2014) also reported higher grain and straw yield with phosphorus application. Under full irrigation treatment, the use of fertilizer alone increases the root/shoot ratio during the cropping period (Table 3).

Table1. Treatments combinations for maize

Treatments	Soil moisture [3)]	Combination [2)]	Descriptions [1)]
1	70%-100%	-M-F-S	No mulch No fertilizer No stress
2		-M+F-S	No mulch Plus fertilizer No stress
3		+M-F-S	Plus mulch No fertilizer No stress
4		+M+F-S	Plus mulch Plus fertilizer No stress
5	55%-65%	-M-F+S1	No mulch No fertilizer Plus mild stress *
6		-M+F+S1	No mulch Plus fertilizer Plus mild stress *
7		+M-F+S1	Plus mulch No fertilizer Plus mild stress *
8		+M+F+S1	Plus mulch Plus fertilizer Plus mild stress *
9	45%-55%	-M-F+S2	No mulch No fertilizer Plus severe stress *
10		-M+F+S2	No mulch Plus fertilizer Plus severe stress *
11		+M-F+S2	Plus mulch No fertilizer Plus severe stress*
12		+M+F+S2	Plus mulch Plus fertilizer Plus severe stress*

[1)] * At seedling stage; [2)] M: Mulch; F: Fertilizer ; S: Full irrigation; S1: Mild stress; S2: Severe stress.
[3)] 70%-100% represent the maximum and minimum moisture content for full irrigation treatments; 55%-65% represent the maximum and minimum moisture content for mild stress treatments; 45%-55% represent the maximum and minimum moisture content for severe stress treatments. Those values represent the percentage of field capacity

Table 2. Irrigation water used in millimeters for different treatments during the growing of maize

Year	DAS[1)]	Amounts of water used for the different treatments[2)]											
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
2005	1	56	56	56	56	56	56	56	56	56	56	56	56
	4	24	24	24	24	24	24	24	24	24	24	24	24
	21	18	18	18	18	18	18	18	18	18	18	18	18
	32	27	26	10	10	5							
	48	32	19	24	23	30	31		25				
	64	27	33	34	34	23	24	34	19	32	38	28	25
	82	38	38	30	25	19	29	32	20	27	23	22	24
	Total	222	214	196	190	175	182	164	162	157	159	148	147
2006	1	18	18	18	18	18	18	18	18	18	18	18	18
	10	24	24	24	24	24	24	24	24	24	24	24	24
	22	07	05	05	05	04	04	05	05	02	06	05	03
	30	23	22	13	19	05	07						
	36	18	22	17	20	21	20	14					
	48	36	29	29	29	26	22	26	31	39	39	37	36
	60	34	25	30	24	21	22	20	26	18	15	23	23
	75	34	28	29	30	29	28	31	30	22	23	10	12
	95	30	33	31	19	23	24	25	27	34	30	29	23
	Total	224	206	196	188	171	169	163	161	157	155	146	139

[1)]DAS: Days after sowing, [2)] T: treatment

Table 3. Biomass yield, root to shoot ratio and water use efficiency of maize in 2005 and 2006

Year	Treatments	Parameters			
		Aboveground biomass ($kg\ ha^{-1}$)	Underground biomass ($kg\ ha^{-1}$)	Root/shoot	WUE($kg\ m^{-3}$)[1)]
2005	-M-F-S	3708.651	509.629	0.13	1.693
	-M+F-S	4161.822	596.148	0.14	1.972
	+M-F-S	4264.859	402.666	0.09	2.204
	+M+F-S	4023.111	517.185	0.12	2.133
	-M-F+S1	6563.985	785.777	0.11	2.442
	-M+F+S1	3129.851	262.518	0.08	2.534
	+M-F+S1	4316.162	548.444	0.12	2.668
	+M+F+S1	6659.606	407.703	0.11	2.877
	-M-F+S2	5005.392	653.037	0.13	2.396
	-M+F+S2	5268.222	695.851	0.13	2.033
	+M-F+S2	5144.419	636.888	0.14	3.085
	+M+F+S2	3463.185	351.851	0.10	2.389
2006	-M-F-S	5182.508	368.562	0.07	1.526
	-M+F-S	6220.572	487.209	0.08	1.794
	+M-F-S	4651.624	781.925	0.16	2.057
	+M+F-S	6295.841	708.049	0.11	2.146
	-M-F+S1	6695.644	619.753	0.09	2.320
	-M+F+S1	4826.834	524.839	0.10	1.815
	+M-F+S1	5351.071	678.419	0.12	2.287
	+M+F+S1	6817.787	608.592	0.08	2.488
	-M-F+S2	5975.377	517.432	0.08	2.315
	-M+F+S2	4812.375	466.469	0.09	2.005
	+M-F+S2	6338.548	583.802	0.09	2.140
	+M+F+S2	6057.767	686.419	0.11	2.620

[1)]WUE, water use efficiency

The application of mulch increases WUE by 30.18 and 34.80% in 2005 and 2006 under full irrigation treatment (Table 3). Mulch mass, evaporative potential and irrigation frequency were greater in 2006 compared with 2005.

Our results are in line with those of Qiang *et al.*(2018), who reported that the effects of mulching on WUE of potato were improved by 28.7% with plastic mulching and 5.6% with straw mulching.

Table 4. pH, available nitrogen and Bulk density of the top soil layer of the plots treatments during the cropping period

Treatments	Sampling time						
	November 2005		June 2006		November 2006 [1)]		
	pH	N($mgkg^{-1}$)	pH	N($mgkg^{-1}$)	pH	N($mgkg^{-1}$)	BD ($g\ cm^{-3}$)
-M-F-S	7.823	41.51	7.838	44.360	7.920	30.383	1.195
-M+F-S	8.330	30.36	7.813	47.872	7.825	34.525	1.215
+M-F-S	8.400	30.10	7.951	39.296	7.948	38.330	1.197
+M+F-S	8.373	31.85	7.948	37.931	7.831	39.500	1.207
-M-F+S1	8.190	41.03	7.903	39.423	7.921	32.676	1.180
-M+F+S1	8.246	35.60	7.856	41.508	7.853	40.381	1.260
+M-F+S1	8.326	49.84	7.926	40.385	7.921	34.345	1.162
+M+F+S1	8.330	37.52	7.841	43.942	7.816	37.718	1.151
-M-F+S2	8.243	45.92	7.795	39.873	7.746	48.607	1.251
-M+F+S2	8.160	36.34	7.746	53.381	7.806	40.904	1.238
+M-F+S2	8.516	30.40	7.886	45.541	7.916	40.381	1.809
+M+F+S2	8.453	30.80	7.701	47.511	7.723	51.544	1.191

1) pH: pH (H_20), N: available nitrogen, BD: Bulk density of the soil

Similarly, Mo *et al.* (2017) reported that maize water use efficiency was increased by 53.3% in black plastic mulch than non mulch condition with alternative ridge and furrow method respectively. In the present study, the use of fertilizer alone, under full irrigation treatment, increases WUE by 16.48 and 17.56% in 2005 and 2006.

Soil parameters: The pH value, available nitrogen and bulk density during the cropping period are presented in Table 4. Analysis of variance (ANOVA) shows that water application significantly ($P<0.05$) affected the soil pH value during the growing period. However, fertilizer application did not have any significant effect on soil pH. In june 2006, the use of fertilizer alone decreases soil pH by 0.32, 0.59 and 0.63% under full irrigation, mild and serious treatments respectively. Similarly, in november 2006, a decrease of 1.2 and 0.86% was observed under full irrigation and mild stress. Continuous use of relatively high rates of nitrogenous fertilizers on kaolinitic Alfisols, especially under cereal monoculture, can reduce soil pH and seriously reduce soil fertility (Juo *et al.*, 1995). The decrease in pH observed after fertilizer application is in conformity with the findings of Aref and Wander, 1998 who observed lowering soil pH due to long term fertilizer applications on the low morrow plots in Illinois. The addition of plant material to soil can cause soil pH to increase, decrease or remain unchanged (Fageria, 1998). In the present study, the application of mulch increases soil pH by 7.37, 1.41 and 0.35% in november 2005, june 2006 and november 2006 respectively. Nitrogen (N) is one of the critical nutrients for crop production and is generally applied in large quantities in form of fertilizer to soils (Kong *et al.*, 2008). However, most plants only utilize less than one half of fertilizer N applied, and the loss of fertilizer N was high (Zhu and Chen, 2002).

In the present study, the application of mulch, water and fertilizer significantly ($p<0.05$) affected available nitrogen during the cropping period (Table 4). Under full irrigation and mild stress, the use of fertilizer alone increase available nitrogen by 7.91 and 5.28% in June 2006. Similarly in november 2006, an increase of 13.63 and 23.58% was observed under full irrigation and mild stress treatments. The interaction of mulch water (M*W) and mulch water fertilizer (M*W*F) were significant in november 2005 and november 2006. Analysis of variance indicated that, mulch, fertilizer, water and their interaction significantly affect soil bulk density at the end of cropping period (Table 4). In the present study, the use of crop residue reduced soil bulk density by 1.53 under mild stress treatment (Table 4).

Our results corroborate the findings of Chatterjee *et al.*, 2016 who stated that application of crop residue mulch significantly reduced the bulk density by 1.3, 1.8 and 1.8% at 0-5, 5-15 and 15-30 cm soil depth, respectively over no mulch. Hari *et al.*, (2013) reported decrease in soil bulk density from 1.47 g cm^{-3} to 1.37 g cm^{-3} in the surface 0-15 cm soil layer and increased in soil organic carbon content from 0.148% to 0.189% in no mulch treatment to in 6 ton ha^{-1} in mulch treatments respectively. The lower soil bulk density was likely associated with improved soil physical conditions created by crop residues and fertilizer application. Inclusion of crop residues especially legumes are known to improve soil physical conditions, as reflected by lower soil bulk density, increased aggregate stability and more infiltration rates (Franco, 1996).

Conclusion

The application of mulch at the rate of 6 t ha^{-1} reduced the amount of water needed to grow maize and increased WUE by 30.18% and 34.80% under full irrigation in 2005 and 2006. The use of fertilizer alone increases underground biomass by 16.98% and 32.19% in 2005 and 2006. Under mild stress treatment, mulch application reduced soil bulk density by 1.53%. Further research should consider conducting this work in the field since in the present study all the parameters were controlled under the ambient green house conditions.

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