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Influence of Irrigation and Fertilizer on the Yield of Maize as Affected by Residue Mulch

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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 this, balanced and integrated use of nitrogen fertilizer and residue mulch enhance the accumulation of soil organic matter, improves soil physical properties and increase crop yield. Hence, influence of irrigation, fertilizer on the yield of maize as affected by residue mulch was examined in a green house. The objective was to determine measures, which if taken, will enhance resistance to drought and increase yield of maize with improved soil conservation. The experiment was laid out in a randomized complete block design with three blocks and twelve treatment combinations. Treatments included three factors: factor a: irrigation in three levels (no stress (a1), mild stress (a2) and severe stress (a3)), factor b: nitrogen fertilizer in two levels (no fertilizer (b1), 240 kg ha^{-1} (b2)) and factor c: residue mulch in two levels (no residue mulch (c1) and 6000 kg ha^{-1} (c2)). Experimental results revealed that mulch application reduced the amount of water needed for irrigation and increased biological yield of maize by 15 and 16.80% under full irrigation in 2005 and 2006 respectively. The use of fertilizer alone increased biological yield in non-mulch treatment under full irrigation by 12.22 and 20.03% in 2005 and 2006 and the interactions of fertilizer mulch and fertilizer water significantly ($p<0.5$) affected grain yield and biological yield of maize in 2005.

Keywords: Irrigation, Fertilizer, Green House, Residue Mulch, Biological Yield of Maize

1. Introduction

Drought is considered as one of the most important factors that limit plant production in arid and semi arid zones [1], where such areas are subjected to a wide range of climate variation as well as climate changes. In addition to this, the percentage of drought affected areas in the world has doubled from the 1970s to the early 2000s and developing countries are the most affected, specially the Sahel region of Africa [2]. Under such conditions, lower yield and lower water use efficiency take place especially under the instability of water amounts from year to year [3]. Therefore, an appropriate management of irrigation is necessary to preserve water resources, quantitatively and qualitatively, and to produce more food with the available water. Irrigation scheduling is one of the most important tools for developing best management practices for irrigated areas [4].

However, the application of irrigation deficit alone does not give positive results regarding crop production or soil quality and under such critical condition, mulching may be one of the suitable alternatives to maintain optimum moisture and thermal environment in the soil. The effects of rice mulch on crop yield and nitrogen use efficiency is inconclusive and has been shown to vary with the characteristics of the site and the climate [5]. Experiences so far have highlighted positive, neutral and negative short-term yield responses to rice mulch. For example, Chakraborty *et al.* [6] reported that rice straw mulch increased wheat grain yield, reduced crop water use by 3-11% and improved Water Used Efficiency (WUE) by 25% compared with no mulch. In contrast, Wang *et al.* [7] reported that application of cereal straw with wide C: N ratio such as rice straw or wheat straw led to soil nitrogen immobilization and inhibited rice growth at early stages with a subsequent decline in rice yield. Gangwar *et al.* [8] found that higher level of nitrogen were required to crops sown under rice straw mulch.

The application of mineral fertilizers in the soil has several effects on the properties of the soil, for example salinity values and soil pH. Akanbi *et al.* [9] asserted that inorganic fertilizers can improve crop yields, soil pH, total nutrient content and nutrient availability, but their use is limited due to scarcity, high cost, nutrient imbalance and soil acidity. Moreover, emerging evidence indicates that integrated soil fertility management involving the judicious use of combinations of organic and inorganic resources is a feasible approach to overcome soil fertility constraints [10]. Combined organic and inorganic fertilization both enhanced C storage in soils, and reduced emissions from N fertilizer use, while contributing to high crop productivity in agriculture [11]. Zhao *et al.* [12] reported that farmyard manure combined with chemical fertilizer management resulted in a higher increase in maize yield, soil organic matter, available N and available P compared with those found under straw manure combined with chemical fertilizer management.

Maize (*Zea mays* L.) is one of the most important crops in the world, ranking third behind rice and wheat [13]. It is now the most widely produced cereal crop with an overall production of approximately 1006.18 million tones [14]. Maize is currently produced on nearly 184 million hectares in 125 developing countries [15]. Information's about the influence of irrigation and fertilizer on the yield of maize as affected by residue mulch under green house conditions are scanty. Thus, the objectives of the study were: (1) To examine the effects of residue mulch, fertilizer in combination with seedling stage drought on maize yield; (2) To investigate the impacts of mulch and water stress and fertilizer on harvest index and harvest ratio of maize.

2. Materials and Methods

2.1. 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 12.26 mg 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.

2.2. Experimental Details

The experimental design is a Randomized Complete Block Design with three replications. Twelve treatments were considered (Table 1). Each plot is 2.25 m x 1.5 m. The seeds were sown at 5 cm depth and 40 x 30 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} to all plots. The first weeding was carried out at two weeks after planting. Rice residues were cut into homogeneous pieces of about 5 cm. This was applied as mulch at the rate of 6 t ha^{-1}, 15 days after maize emergence to six plots in each block. 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, urea fertilizer ($CO(NH_2)_2$) at the rate of 240 kg ha^{-1} was applied to six plots in each block.

Pipes of 5 cm diameter, 15, 35 and 55 cm length were inserted in plots. 5 cm of each pipe was kept above ground to avoid water entry during irrigation. These pipes were used for soil moisture measurements and remained closed with covers except during measurements.

Soil moisture content at 0-60 cm depth was measured with neutron probe meter (MPM-160B) at intervals of 7-10 days. The moisture absorbed from the soil for a given interval was taken as the decrease in soil moisture in 0-60 cm depth interval. Evapotranspiration for the same interval was considered to be the total amount of moisture absorbed from the soil plus irrigated water.

Harvesting was done on October 17^{th} each year. For analysis, shoot biomass was taken, oven dried for 72 hours at 65°C and thereafter weighed.

Table 1. *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 *

Treatments	Soil moisture [3)]	Combination [2)]	Descriptions [1)]
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

The harvest index (HI) was calculated as:

$$\mathrm{HI} = \frac{\text{Grain yield}}{\text{Grain yield+Straw yield}} \text{ (Ali et al. [16])}$$

The harvest ratio was calculated as:

$$\mathrm{HR} = \frac{\text{Grain yield}}{\text{Straw yield}}$$

2.3. Statistical Analyses

All statistical analyses were performed using General Linear Models (GLM) in SPSS, Version 20 package. Three way ANOVA analyses were carried out in all twelve treatments to test explicitly the effects of deficit irrigation, mulch and fertilizer on growth parameters of maize. Water application, mulch and fertilizer were treated as fixed factors in all the analyses, while plant biomass, shoot biomass, root biomass, total biomass yield, grain yield as dependent variables. Correlation analyses were carried out between number of leaves and plant diameter, plant height and leaf area.

3. Results

3.1. Irrigation Water Used

Table 2 shows the Irrigation water used for different treatments during the growing of maize. Mulch application reduced the amount of water needed to grow maize under full irrigation, mild and serious treatments. The Irrigation water used was higher for no mulch no stress treatments (248.57 mm) compared with plus mulch no stress (212.71 mm). Similar pattern was observed under mild and severe treatments (Table 2).

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

Year	DAP[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)]DAP: Days after planting, [2)] T: treatment, See Table 1 for details of treatments.

3.2. Biological Yield, Straw Yield and Grain Yield

The effect of the treatment applications (irrigation, mulching and fertilizer) on maize dry matter and yield is as shown in Table 3. Results show that the watering regime has no significant ($p<0.05$) effect on straw yield, biological yield and grain yield of maize. However, mulch significantly ($p<0.05$) affect yield of maize. The effect of fertilizer is only significant ($p<0.05$) in 2005, which is the first year of cropping. The interactions of fertilizer mulch and fertilizer water significantly ($p<0.5$) affects straw yield and biological yield of maize in 2005. During that period, the highest biological yield (6563.99 kg ha^{-1}) was obtained under no mulch mild stress no fertilizer (-M+S1-F) and the lowest biological yield (3129.85 kg ha^{-1}) was recorded with no mulch mild stress plus fertilizer (-M+S1+F) treatments. In 2006, the highest biological yield (6817.79 kg ha^{-1}) and the lowest biological yield (3982.50 kg ha^{-1}) were obtained under plus mulch mild stress plus fertilizer

(+M+F+S1) and no mulch no fertilizer no stress treatments (-M-F-S) respectively.

***Table 3.** Biological yield, straw yield and grain yield (kg ha^{-1}) of maize in 2005 and 2006.*

Treatments[1]	2005			2006		
	Biological yield	Straw yield	Grain yield	Biological yield	Straw yield	Grain yield
-M-F-S	3708.65	2773.35	251.17	3982.50	3394.73	602.45
-M+F-S	4161.82	3022.10	284.53	6220.57	3656.18	1207.05
+M-F-S	4264.86	2803.79	673.56	4651.62	3949.39	1892.71
+M+F-S	4023.11	3065.13	220.22	6295.84	3947.97	835.94
-M-F+S1	6563.99	4221.72	827.01	6695.64	3850	1495.27
-M+F+S1	3129.85	3085.13	213.52	4826.83	3977.44	1118
+M-F+S1	4316.16	3129.97	298.68	5351.07	3821.95	611.52
+M+F+S1	4536.34	3721.48	350.64	6817.79	4217.13	1234.63
-M-F+S2	5005.39	3732.70	533.24	5975.37	3628.32	1040.75
-M+F+S2	5268.22	3909.73	326.71	4812.38	3190.08	553.85
+M-F+S2	4497.33	3253.69	292.56	6338.55	3980.94	1150.59
+M+F+S2	3463.19	2641.78	119.41	6057.77	3899.08	860.24

[1] See Table 1 for details of treatments.

3.3. Harvest index and harvest ratio

The harvest index and harvest ratio of maize are presented in Table 4. In 2005, the lowest harvest ratio (4.52%) was obtained under plus mulch plus fertilizer plus severe stress treatment and the highest harvest ratio (24.02%) was obtained under plus mulch no fertilizer full irrigation. While in 2006, the lowest harvest ratio (16%) was obtained under plus mulch no fertilizer plus mild stress treatment and the highest harvest ratio (47.92%) was obtained under plus mulch no fertilizer full irrigation treatment. Similar pattern was observed for harvest index.

***Table 4.** Harvest index and harvest ratio of maize in 2005 and 2006.*

Treatments[1]	2005		2006	
	Harvest index (%)	Harvest ratio (%)	Harvest index (%)	Harvest ratio (%)
-M-F-S	6.77	9.06	15.13	17.75
-M+F-S	6.84	9.41	19.40	33.01
+M-F-S	15.79	24.02	40.69	47.92
+M+F-S	5.47	7.18	13.28	21.17
-M-F+S1	12.60	19.59	22.33	38.84
-M+F+S1	6.82	6.92	23.16	28.11
+M-F+S1	6.92	9.54	11.43	16
+M+F+S1	7.73	9.42	18.15	29.28
-M-F+S2	10.65	14.29	17.42	28.68
-M+F+S2	6.20	8.36	11.50	17.36
+M-F+S2	6.51	8.99	18.15	28.90
+M+F+S2	3.45	4.52	14.20	22.06

[1] See Table 1 for details of treatments.

3.4. Correlations Between Yield Parameters

Correlations between maize dry matter and yield in 2005 and 2006 are presented in Table 5. It was found that most correlations between the yield characteristics were highly significant ($p<0.01$) and also that correlation coefficients were high. High positive correlations exist between biological yield and straw yield and between biological yield and grain yield. However, there is no significant correlation between straw yield and grain yield.

***Table 5.** Correlations between yield parameters in 2005 and 2006.*

Year	Parameters	Parameters		
		Biological yield	Straw yield	Grain yield
2005	Biological yield	1000	0.855**	0.511**
	Straw yield		1000	0.158
	Grain yield			1000
2006	Biological yield	1000	0.704**	0.628**
	Straw yield		1000	-0.028
	Grain yield			1000

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

4. Discussion

Application of residue mulch is primarily aimed to conserve soil moisture, suppress weeds and improve soil quality. According to Chakraborty *et al.* [17], 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. The rate of drying of soil was slow, resulting in water availability for relatively longer period during crop growth and development [17]. The effect was particularly pronounced during dry periods where no irrigation was given to the crop, or no rain occurred. In the present study, we found that, mulch application reduced the amount of water needed to grow maize. Results obtained in this study agrees with those of Bhardwaj and Sindhwal [18], who reported that the addition of residue mulch resulted in significant increase in soil water content and reduced runoff. The increase in soil moisture was effective in ensuring better germination and higher yield. In the presence of moisture, nutrients were more available to plant roots, thus leading to higher grain yield. Our results are in line with those of Liu [19], who reported that mulch increases the soil moisture and nutrients availability to plant roots, in turn, leading to higher grain yield. Chaudhary *et al.* [20], examined the effect of three rates of mulches that is 2, 4 and 6 tones ha^{-1} and noted that mulch application appreciably improved the grain and straw yields. The application of mulch leads to improve net return of crops through maximizing yield and water productivity [21, 22]. Mo *et al.* [23], reported that maize grain yield and water use efficiency was increased by 58.8 and 53.3% in black plastic mulch than non-mulch conditions with alternate ridge and furrow method respectively. In the present study, we found that, mulch application increases biological yield of maize by 15% under full irrigation. These results corroborate the findings of Tolk *et al.* [24] who reported that mulch increased grain yield by 17% and above ground biomass by 19%. Shen *et al.* [25] found that, under rain fed conditions in northern China, straw mulching could significantly enhanced the grain yield of summer maize. Similarly, Xu *et al.* [26] 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.

Different irrigation regimes were found to have significant ($p<0.05$) effect on the straw yield. Straw yield exhibited the tendency of increasing with the influence of irrigation levels. This might be due to the luxuriant vegetative growth in terms of plant height and number of tillers per plant. Meskelu *et al.* [27] reported that application of lower irrigation depth leads to lighter seed weight of wheat under irrigation. In the present study, we found that, fertilizer application significantly affects biological yield of maize. Similar results were also reported by Jiang *et al.* [28]. Ahadiyat *et al.* [29] also reported higher grain and straw yield with phosphorus application.

The interactions of fertilizer mulch and fertilizer water significantly affect straw and biological yield of maize in 2005. Better yield of maize with balanced application of organic manure and inorganic fertilizers may be attributed to improvements in soil physical properties along with sufficient supply of nutrients from farmyard manure and inorganic fertilizers. Increases in yield due to inorganic and organic fertilizers have been reported by many researchers [30, 31]. The lowest yield obtained during the cropping period might be due to the condition in the green house. These are lack of wind and excessive temperature (more than 40°C at mid day) which hampered fertilization and seed formation. Combined soil water temperature during the reproductive period can substantially reduce final grain yield [32].

In the present study, we found that, most correlations between the yield characteristics were highly significant ($p<0.01$) and also that correlation coefficients were high. These high levels of correlations indicate that the physiological characteristics were highly dependent on each other.

5. Conclusion

Residue mulch applied at the rate of 6 t ha^{-1} reduced the amount of water needed to grow maize. Mild stress at seedling stage produces higher yield. Water deficit at early stages of growth induced minimal reduction in maize yield.

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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