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Effect of Irrigation Water Amounts and Nitrogen Fertilizer Levels on Teosinte Productivity and Optimal Economic N-Rates under Salinity Stress

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ABSTRACT

The teosinte plant is one of the most important fodder crops that is affected by drought and nitrogen supply, and therefore the optimal supply of N- fertilization may be affected by the amount of irrigation water added to teosinte plants to obtain an economic crop. Two field experiments were done to study the effect of irrigation amount at three levels (100%, 80% and 120%) and nitrogen fertilizer levels (140, 210 and 280 kg N ha^{-1}) on the yield productivity of teosinte and determined the optimal and economic optimal N rate as affected by irrigation amount levels, and water relations. The results showed that the highest values of the fresh and dry weight of cuts, as well as plant height and stem diameter, were obtained when applying the full irrigation rate with full irrigation and 280 kg N ha^{-1}. The results also showed that a 20% decrease in the irrigation rate led to a deterioration in the values of those parameters. Although the results showed that the full irrigation amount more saved water at two seasons under various levels of nitrogen. Moreover, all water relationships gave the best mean values for actual evapotranspiration, water utilization and use efficiencies also, higher application efficiency values at full irrigation and 280 kg N-levels than the other treatments. Also, the results showed that the highest economic yield was obtained when using 120% of the recommended irrigation water, with the use of 496.75 kg N ha-1. Despite this, it is recommended to use the full irrigation rate with the use of 345.03 kg N ha-1, as it gave an economic yield less than that with use 120% of the recommended irrigation amount by 2.19% while providing nitrogen fertilization by 43.97%, thus preserving the environment Pollution by loss of nitrogen fertilization through agricultural drainage or volatilization.

KeywordsIrrigation, Nitrogen, Teosinte, Drought, Salinity, Stress, Optimal nitrogen

Introduction

The most important abiotic stress for agriculture, and for teosinte specifically, is drought. There is variability for drought tolerance in maize but, unlike teosinte, it has not been bred by drought

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tolerance. An example of the problem is provided [1],who acknowledge that climate change is a major concern for humanity. As climate projections for temperate regions indicate that temperature will increase, and precipitation will decrease over a few decades subsequently impacting water availability negatively. Hirich et al. [1] found that the growing season for maize would be shortened by 20 days due to increasing temperature decreasing water requirements by 13%. However, crop evapotranspiration is projected to increase by 15% resulting in an overall yield reduction of 2.5% by the century's end. Among the most important factors that affect drought in crops, in addition to climatic factors, are the lack of irrigation water or the irregularity of the irrigation process.Understanding crop water needs is essential for irrigation scheduling and water saving measures in an arid and semi-arid region because of its limited water supply.

Teosinte (*Zea mexicana Schrad* L.) is one of the most important summer forage crops which closely related to maize in most allometric trait. It has the advantage of tillering and regeneration as a fodder crop [2]. Teosinte and maize growth and yield, are most sensitive to nitrogen application under moisture stress conditions. Improper fertilizer and water management are the two major factors adversely affecting maize growth and productivity under dryland conditions. The main objective in agriculture production, so far, focused mostly on the increase of yield and production [3,4].

In Egypt, the water resources are limited and restrict many crops production especially in newly reclaimed lands due to the establishment of intensive agricultural production in the Nile Delta and valley area. The agricultural area consumes more than 84% of the available water resources [5]. Three factors affect the agricultural water use such as the water needs (evapotranspiration) by the crop, water availability, and water holding capacity of the soil [6,7]. Also, climate changes, such as altered precipitation and temperature systems, have had negative effects on crop quantity and yields. Seasonal global temperatures have increased, with even larger changes observed in several regions

Fertilizer application is one of the most effective and practical ways to control and improve yield and nutritional quality of crops for human consumption. In the current food production scenario across major cropping systems of the world, crop yield is limited more by availability of nitrogen (N) and water resources rather than by the crop genetics [8,9]. Increased plant nitrogen adsorption was observed under irrigation only in drought years, and it was decreased in optimal or extremely wet years [10].

Nitrogen (N) is one of the critical nutrients for crop production and is generally applied in large quantities to soils [11]. The use of mineral nitrogen fertilization results in improved growth, higher biomass, and yield, and facilitates the metabolism to give a higher amount of protein in maize plant tissue [12,13]. Nitrogen directly influences the amino acid composition of protein and thereby the nutritional quality of the economic production.

In the last several decades, the uses of irrigation and fertilization have led to increases in crop production and food security [14]. In regions that have water-scarce, high yield and improved

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water use efficiency (WUE) of crops can be obtained if water and nitrogen (N) are properly applied. While water and N have been the subject of research worldwide, studies are needed to advance our understanding of the complexity of their interaction [15]. Irrigation and fertilization are widely used for the production of food and forage crops, mostly because it alters the farm environment by changing the soil water contents and soil nutrients which result in the increase of soil fertility and growth environment. Therefore, it would be necessary to improve the water use efficiency and fertilizer production efficiency in arid and semiarid regions, especially for field management purposes [16]. The interaction of nitrogen and irrigation has significant effects on maize biomass yield [16]. Also, Nilahyane et al. [15] showed that irrigation water, N, and application timing significantly affected the growth and DM yield of maize, especially at late vegetative and mid reproductive growth stages [15].

The coupling effect of water and fertilizer is not distinct and more fertilizers can be used to compensate for the shortage of water under limited water resources. Meanwhile, through the coupling of water and fertilizer, N affects water consumption. But we still have limited information about the effects of different measures of controlling the supply of water and fertilizer on teosinte fresh and dry yield and optimal and economic optimal nitrogen rate. Thus, the present study's aim was to focus on the relationships between the irrigation amount and N fertilizer input levels on teosinte fresh and dry yield and optimal and economic optimal nitrogen rate.

Materials and Methods

Experimental setup

Two field experiments were setup on clay soil at El-Serw Agric. Res. Station Farm, Damietta Governorate, Egypt. The farm is located at 31o 22' N latitude and 31o 64' E longitude during the two summer seasons 2020 and 2021 to study the effect of irrigation amount at three levels (100%, 80% and 120% from irrigation water requirements) and nitrogen fertilizer levels (140, 210 and 280 kg N ha^{-1}) on the yield productivity and its quality of teosinte (*Zea mexicana*, L.) genotype Damietta.

The analysis of the surface soil layer (0 to 60 cm) at the start of the experiments was as follows: soil saturation extract for EC analysis (ECe) 6.55 dS m^{-1} with pH (H_2O, 1 soil to 2.5 H_2O) value of 8.2 and contained 5.21 g kg^{-1} Walkley-Black carbon, 0.30 g kg^{-1} total nitrogen by the Kjeldhal method [17], 7.97 mg kg^{-1} 0.5 M NaHCO3-extractable P [18] and 448 mg kg^{-1} 1 N NH4OAc-extractable K [19]. The soil study experiment is classified as moderately saline soil (ECe 8-16 dS/m) based on the USDA classes [20]. The experimental farm was irrigated from the El-Serw drainage, which was irrigated from a point approximately 20 km from the beginning of the drainage (EC 1.2:1.4 dS m-1, SAR 10.5:11.3), so the irrigation water classification is considered to be water that increases salinity problems [13,21]. Some hydro physical properties of the soil at the experimental site are presented in Table 1.

According to the Köppen climate classification, the area has an arid climate with dry hot summers and wet cool winters [22]. Meteorological conditions (mean precipitation (mm), surface

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pressure (kPa), percentage humidity (Table 2), and maximum, minimum, and main temperature, dew/forest point, and wet bulb temperature (°C) at the teosinte cultivation experimental site during the two winter seasons (Figure 1).

Experimental design

The treatments were laid out in a strip-plot experimental design with three replicates, the plot size was 6x7 m^2. The seeds were drilled in hills 20 cm apart with 20 kg/ fed seeding rate. Planting date was 23^{rd} and 21^{st} May in 1^{st} and 2^{nd} seasons, respectively. The preceding winter crop for both seasons was berseem in the two seasons. Irrigation treatments were allocated at the vertical plots, while the assessed nitrogen fertilizer in the form of ammonium nitrate (33.5%) levels were occupied the horizontal plots as follows: Vertical plots (Irrigation levels, I): 1 = 100% Irrigation requirements (Full Irrigation), 2 = 80% from irrigation requirements and 3 = 120% from irrigation requirements (the irrigation treatments were started after the life irrigation). Horizontal plots (Nitrogen fertilization rates, N): N1 = 140 kg N ha^{-1}, N2 = 210 kg N ha^{-1} and N3 = 280 kg N ha^{-1}. The nitrogen doses were divided into three equal doses. The first dose was added after 21 days from sowing, the second and the third doses were added after the first and the second cuts, respectively.

Agricultural practices were done as recommended by forage Research Department. Three cuts were taken during each summer season after 55, 95 and 120 days from sowing.

Agronomic characters:

- Fresh forage yield (t ha^{-1}); was weighed in kg/ plot then converted into ton/ fed.
- Dry forage yield (t ha^{-1}); 100g plant samples from each plot were dried at 105°C till constant weight and dry matter percentage (DM %) was estimated then dry forage yield (t ha^{-1}) was calculated by multiplying fresh forage yield (t ha^{-1}) X DM%.
- Plant height (cm), length of the main stem from soil surface to stem-tip.
- Stem diameter (cm).

Water relations:

1. Actual evapotranspiration (Eta) “cm ha^{-1}). Gravimetric soil samples from 0.15 m to 0.60 m depth were collected after planting, before and after irrigation and after cutting to determine the actual water consumption. Total consumed water was calculated according to the equation suggested by Israelsen and Hansen [23] as follows:

$$ET_a = \sum_{i=1}^{i=4} \left(\frac{\theta_2 - \theta_1}{100}\right) X\ \rho_b\ X\ D$$

Where: ETa= actual evapotranspiration (cm). i= soil layer. n= total number of soil layer. 2= (%) soil moisture on mass basis after irrigation. 1= (%) soil moisture on mass basis before irrigation. b= soil bulk density. D= layer depth (cm).

2. Applied water application (Ea), according to ICID [24] as:

$$E_a = \frac{ET_a}{\text{Applied irrigation water}}$$

3. Water utilization (WU_tE) efficiency values were calculated to the equation given by Michael [25].

$$WU_tE = \frac{\text{Yield } (kgha^{-1})}{\text{Applied irrigation water } (m^3ha^{-1})}$$

4. Water use efficiency were calculated according to Jensen [26] as

$$WUE = \frac{\text{Yield } (kgha^{-1})}{\text{TotalConsumed water } (m^3ha^{-1})}$$

Optimal and economic optimal N rate

Optimum N rates Quadratic N response curves to fertilizer N rates were constructed for each irrigation amount using three N rates (Table 3 and Figures 2, 3 and 4). Optimum N dose (Nop) and economic optimum N (Neop) dose were calculated using the information from quadratic regression equations, the market price of teosinte fresh yield (US$ 0.03/kg and cost of fertilizer N (US$. 0.41/kg of N): The Neop was defined as the rate of N application where US $1 of additional fertilizer N returned US $1 in fresh yield, and was based on the assumption that fertilizer N was the only variable cost and all other costs were fixed. The ratio of the cost of fertilizer N to the price of teosinte fresh yield was referred to as cost: price ratio (CPr).

The Nop and Neop were calculated according to Thind et al. [27] and Mosaad et al. [13] using the following equations:

$Y = cX^2 + bX + a$ (1)

where Y is fresh yield (kg ha^{-1}), x is the fertilizer N rate (kg ha^{-1}), and a, b, c is regression parameters.

Nop = -b / 2c (2) Neop = (CPr – b) / 2c (3)

Statistical analysis:

Data were statistically analyzed according to procedures outlined by Snedecor and Cochran [28] using MSTAT computer program V.4. (1986) Bartlett's test was done to test the homogeneity of error variances. The test was significant for all traits; thus, data were not combined in both seasons.

Results and discussion

Agronomic traits

Fresh and dry yields:

Data in Table 3 show that there were significant differences among the studied traits i.e.,

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irrigation amount on fresh and dry yields. Fresh and dry yield increased with cut two in the two seasons. Full irrigation recorded the highest means value of fresh yield (14.76 and 14.55 t ha^{-1}, in the 1^{st} and second seasons respectively) in the third cut, that is true for dry matter (2.429 and 2.712 t ha^{-1} in the two seasons). Decreasing irrigation with 20% decrease the highest mean value (330%) in the first season in the second cut and (32.8 %) in the second one. Also, increasing water irrigation amounts with the same percent decrease the highest fresh and dry yield (30.8 and 20.9% in the two seasons) for the second cut. Decrease or increase irrigation amounts with ±20% recorded lowest means for fresh and dry yields. Regarding to total forage of teosinte, full irrigation achieved the heaviest total yield (45.90 and 43.88 t ha^{-1} in the two seasons, respectively) followed by +20% accesses water irrigation while, decreasing water irrigation e.g., -20% recorded the last value of total fresh weight of forage teosinte. Data of total dry matter yield of teosinte recorded the same trend.

Regarding to N-fertilizer rates, Nitrogen in various levels affected significantly fresh and dry yields in all cuts (Table 3). The highest mean of adding nitrogen fertilizer recorded the highest means (45.24, 44.10 and 7.221, 7.514 t ha^{-1}) for total fresh and dry yields in the 1^{st} and 2^{nd} seasons respectively. Nitrogen (N) is an essential nutrient and key limiting factor in crop production of different agro-ecosystems. Moreover, Influencing of N-fertilizer levels on total fresh and dry yields recorded the highest value when the plots received 280 kg N ha^{-1}.

Interactions between the studied traits recorded the significance of difference on fresh and dry yields at 0.05 levels of confidence (Table 3). The highest means (23.50, 20.52, 3.812 and 3.674 t ha^{-1}) recorded for fresh and dry yields in the two seasons in the second cut, respectively.

Data in Table (3) showed the effect of water amounts and N-fertilizer rates on fresh and dry yields over cuts. The heaviest weight over cuts of total fresh and dry yields (55.74, 51.62 and 9.098, 9.148 t ha^{-1} in the first and second seasons, respectively) came from the treatment of full irrigation and the highest N-rates followed by +20% water applications and -20% water irrigation at the same N-rates came the last treatment for the yield of fresh and dry.

The reduction of yield and yield component under waters stress could be due to numerous reasons including decrease of photosynthesis efficiency, leaf area, net assimilation production, and reduction of water and mineral absorption by the root which ultimately decline developmental and vegetative growth. The results indicate that increasing irrigation intervals to 120% reduced all the studied characteristics likely due to water stress deficit. Inadequate available soil water reduces the metabolic activity of maize, decreases its dry matter accumulation, and reduces its photosynthetic level by reducing the chlorophyll content in leaves [29]. Our results show that reduced irrigation by 20% reduces the highest mean value (30%) in the first season in the second cut and (20%) in the second cut. Increasing irrigation amounts by the same percentage also reduce the highest fresh and dry yield (19 and 29 percent in the two seasons) for the second cut. Reduce or increase irrigation amounts, with 20% being the lowest recorded mean for fresh and dry yields.

Further, water stress had a greater effect on the growth and development of maize through the

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seedling stage than the other three stages. Water stress reduced growth and biomass due to decreased intercepted photosynthetically active radiation and radiation-use efficiency. These effects extended into the reproductive stage and finally decreased total gain weight and yield [30]. Water deficit stress through the later vegetative and maturation stage directly decreased yield and its components. Yield was reduced after water-deficit stress occurred during the late vegetative stage and was exacerbated by additional stress during the maturation stage. In all treatments, yield decrease was proportional to the severity of the water stress. However, water stress used had a larger effect on maize yield during the maturation stage than during the late vegetative stage [31].

In terms of nitrogen fertilizer rates, nitrogen at various levels had a significant impact on fresh and dry yields in all cuts. In the first and second seasons, the highest mean of adding nitrogen fertilizer recorded the highest means for fresh and dry yields. Nitrogen (N) is an essential nutrient and key limiting factor in crop production of different agro-ecosystems. Nitrogen is the major nutrient required by pearl millet under agri-horti system which positively increases the growth attributes and improve the yield [32].

Stem diameter and plant height:

Recording data in Table 4 achieved the significant of differences for stem diameter and plant height (cm) under different water irrigation amounts. The thickest values of stem diameter (1.85 and 1.80) and tallest plants (153.11 and 151.73 cm) recorded from cut 2 under full water irrigation in the first and second seasons respectively. A change in water irrigation amounts with ±20% decrease stem diameter or plant height.

Nitrogen fertilizer rates affected significantly stem diameter and plant height. The thickest stem and tallest plant obviously from cut2 under the highest level of nitrogen while, the thinnest stem diameter and plant height recorded from the plots received 140 kg N/fed. The increase in N application, the plant photosynthesizing area, and the assimilate production were increased, therefore caused more plant height, more number of shoots per plant, greater leaf area/plant and thus increased fresh forage weight per plant [33,34]. Moreover, Cho et al. [35] have also reported significant effect of nitrogen application on stem diameter of pearl millet. Plant diameter is controlled by the genetic makeup of the species and the environment to which the plants are subjected during the growth and development. Moreover, these results may be due to the effect of nitrogen fertilization in pushing growth of pearl millet and the increments in inter-node length or/and number of internodes, number of tillers plant^{-1}. These findings are in harmony with those obtained by Ayub et al. [36].

Regarding with the interaction among water irrigation amounts and nitrogen fertilizer levels, there were significant differences in all cuts except the third cut for stem diameter character and second cut for plant height. The thickest stem diameter was (2.81 and 2.93 cm in the second cut in the 1st and 2nd seasons, respectively) under full irrigation and the highest nitrogen rates. Whereas, the tallest plant recorded in the two seasons in the third cut under full irrigations amounts and the highest rate of nitrogen fertilizer. These results indicated that using 100%

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irrigation amount resulted increasing in yield with the highest dose of N-fertilizer.

Optimal and economic optimal N rate

The proportion of variability (R^2) for relationships between nitrogen fertilization rates and teosinte total fresh yield was close to 1.00 ($P < 0.01$) explained that the quadratic model could adequately describe the teosinte fresh yield response to nitrogen fertilization rate. Table 5 showed that optimum and economic optimum N rates varied by different levels of irrigation amount from 409.98 and 380.40 kg N ha^{-1} at 80% of recommended irrigation amount, 360.92 and 345.03 kg N ha^{-1}at 100% of recommended irrigation amount and 530.25 and 496.75 kg N ha^{-1}at 120% of recommended irrigation amount. While teosinte total fresh yield (t ha^{-1}) at optimum and economic optimum N rates by different levels of irrigation amount was 38.83 and 38.62 t ha^{-1} at 80% of recommended irrigation amount, 56.01 and 55.90 t ha^{-1}at 100% of recommended irrigation amount and 57.36 and 57.13 t ha^{-1}at 120% of recommended irrigation amount.

An increase in the amount of irrigation water from the recommended rate of 20% resulted in an increase in the optimum rate of nitrogen as well as the economic optimum rate at 409.98 and 380.40 kg N ha^{-1}, respectively. This is attributed to the effect of low irrigation water, which leads to a drought of the soil and plants, which leads to a high loss of nitrogen fertilization by volatilization due to drought. Soil water affects nutrient transformation from unavailable to available form or vice versa, and thereby the total uptake amount. It also influences the availability of applied nutrients and efficiency through its effect on various nutrient loss mechanisms such as volatilization, nitrification, and/or urease hydrolysis [37]. Also, the increase in the amount of irrigation water from the recommended rate of 20% led to a very high increase in the optimum rate of nitrogen as well as the economic optimum rate at 530.25 and 496.75 kg N ha^{-1}, respectively. However, this is due to the effect of increasing the irrigation water over the recommended amount, which also leads to a high loss of nitrogen fertilization by escaping with the excess water to the agricultural drainage channels. Rong and Xuefeng [38] indicated that excess N fertilizer and irrigation application rates have been provide for crop, and cause more NO_3 leaching.

While the optimum rate of nitrogen and the economic optimum rate of nitrogen at the recommended amount of irrigation water is 360.92 and 345.03 kg N ha-1, respectively, giving a predicted fresh yield of about 56.01 and 55.90 t ha-1, respectively. This yield is higher than the predicted yield at 80% of the recommended amount of irrigation water when using the optimum rate of nitrogen and the economic optimum rate of nitrogen of about 30.68% and 30.91%, with savings in mineral nitrogen fertilization of 13.59 and 10.25%, respectively. While it decreased the yield at 120% of the recommended amount of irrigation water by 2.4% and 2.19%, with savings in mineral nitrogen fertilization of 46.92 and 43.97%, respectively. Therefore, it is preferable to use 100% of the recommended amount of irrigation water with a use of 345.03 kg N ha^{-1} to achieve the highest economic yield in addition to saving the losses from mineral nitrogen fertilization through agricultural drainage or volatilization, thus preserving the environment from

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pollution.

Applied irrigation water and actual evapotranspiration:

Impact of irrigation treatments on amount of applied water and actual evapotranspiration values are presented in Table 6. Results revealed that using 100% irrigation amount saving about 20.1%, 19.6% & 19.8% in the 1st seasons and 19.7, 20.4% & 20.1% in the 2nd season at the three nitrogen doses as compared to 120% irrigation water.

Also, the results showed that average actual evapotranspiration values for a different amount of water treatments were 2.7%, 12%& 6.8% in the first season while in the second season the values were 2.5%, 4.3% & 4.3% under different nitrogen levels as compared 100 % to 120% irrigation water.

Our study shows that when compared to 120 percent irrigation water, using 100% irrigation water saved roughly 20.1, 19.6, and 19.8% in the first season and 19.7, 20.4, and 20.1% in the second season at the three nitrogen doses. These results are in agreement with those reported by Atta and Ewis *et al.,* whose, they stated that applying full irrigation practice significantly increased grain yield of maize [39,40]. Moreover, Gomaa et al. [41] reported that the irrigation every 10 days increased 100-maize grain weight by 14.29 and 16.67% as compared with interval irrigation 20 days in the first and the second seasons, respectively. While irrigation every 15 days increased biological yield by 12.17 and 10.13%, straw yield by 13.38 and 11.97%, as compared with interval irrigation 20 days in the first and the second seasons, respectively [41].

In addition, the results showed that the average actual evapotranspiration values for different amounts of water treatments were 2.7, 12, and 6.8% in the first season, and 2.5, 4.3, and 4.3% in the second season when comparing 100 to 120% irrigation water. These results agree with [42]whose, declared that irrigation differentiation was made upon crop evapotranspiration measured on the lysimeters, water was then applied at 100 and 60% of ET. Full irrigation treatment (I-100) was managed for high productivity, whereas deficit irrigation treatment (I-60) was maintained at 60% of field capacity. Water stress was applied continuously during the growing cycle [42].

Water utilization efficiency (WU_tE), water use efficiency (WUE) and irrigation water application (Ea):

Water utilization efficiency (WUtE) values for teosinte fresh weight yield as affected by the tested variables during 2020 and 2021 growing season are presented in Table 5. Results showed that average water utilization efficiency (WUtE) values were affected by irrigation treatments and nitrogen level treatments. The obtained results in Table 7 indicate that the average water utilization efficiency (WUtE) as affected by irrigation treatments and N-fertilizer rates in the two seasons were 6.68, 7.21&7.88 and 6.54, 7.15 & 7.66 kg m^{-3} in the first and second seasons, respectively.

While, the results of water use efficiency means were 8.0, 8.7 & 9.5 and 7.8, 8.9 and 9.2 kg fresh weight for 100% full irrigation in the two seasons under application of N-fertilizer doses.

Data showed higher application efficiency mean values, differed from 0.83 to and 0.83 to 81% at 140 to 280 N-rates than those in 100% to +20% water application.

Efficiency water utilization is a limiting factor to crop production. The results of our study revealed that irrigation treatments and nitrogen level treatments had an effect on average water utilization efficiency (WUtE) values. Also, the results show that the average water utilization efficiency (WUtE) as affected by irrigation treatments and N-fertilizer rates in the first and second seasons was 6.68, 7.21&7.88 and 6.54, 7.15&7.66 kg m^{-3}, respectively. These results collaborate with Ewis et al. [40] whose, reported that WUtE was positively responded to increasing nitrogen level up to 357.14 kg N ha^{-1} which mainly due to the effect of nitrogen on improving the growth of roots and shoots of maize in turn improved water absorption from soil.
While the results of water use efficiency means were 8.0, 8.7, and 9.5 and 7.8, 8.9, and 9.2 kg fresh weight for 100 percent full irrigation in the two seasons when N-fertilizer doses were applied. The obtained results agree with Shi *et al.*whose, showed WUE was higher in the dry-cultivation treatment since yields decreased relatively less than the supply of irrigation water [43]. However, higher WUE can be achieved by relating deficit stress at the late vegetative stage somewhat than maturation stage [44].
Data, on the other hand, revealed higher application efficiency mean values ranging from 0.83 to and 0.83 to 81% at 60 to 120 N-rates than at 100% to 120% water application. The high irrigation water application (Ea) values under the conditions of the experiment were due to precise land leveling na proper selection of plot size for irrigation teosinte under clay soil conditions [45]. These results declared that adding water at 100% (full irrigation) may improve application efficiency. This is logic and expected result and it is attributable to more irrigation events applied under full irrigation, similar results were obtained by Yousri and Ewis et al. [40] whose, stated that applying full irrigation practice significantly increased grain yield of maize [39,40].

Conclusions

Although all water relationships gave the best mean values for actual evapotranspiration, water utilisation and use efficiencies, it also had higher application efficiency values at full irrigation with 280 kg N-levels than the other treatments. Furthermore, the results revealed that the maximum economic yield was obtained while using 120% of the recommended irrigation water with 496.75 kg N ha-1. Despite this, it is recommended to use the full irrigation at 100% with 345.03 kg N ha-1 because it yielded a lower economic yield than using 120% of the recommended irrigation of only 2.19% while providing nitrogen fertilisation of 43.97%, preventing pollution from nitrogen fertilisation loss by agricultural drainage or volatilization.

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Table 1: Field capacity, wilting point available soil moisture and bulk density values for the soil at the experimental site.

Soil depth (cm)	Field capacity	Wilting point (%)	Available water (%)	Bulk density (g/cm^3)
0-15	48.67	27.07	21.60	1.11
15-30	46.32	25.99	20.33	1.25
30-45	44.10	24.00	20.10	1.30
45-60	40.65	22.77	17.88	1.39
Average	44.93	24.95	19.97	1.26

Table 2. Average Precipitation Corrected (mm), Surface pressure (kPa), Relative Humidity (%) and Wind speed range (m s^{-1}) of experimental site during summer seasons 2020 and 2021.

Month	**Precipitation Corrected (mm)**		**Surface Pressure (kPa)**		**Relative Humidity at 2 Meters (%)**		**Wind Speed at 2 Meters (m s^{-1})**	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
2020								
May	0.005	0.023	101.299	0.309	60.149	6.404	3.147	0.946
June	0.001	0.006	100.987	0.225	49.903	5.892	3.338	0.766
July	0.000	0.000	100.602	0.176	51.847	3.157	3.147	0.548
August	0.000	0.000	100.617	0.141	53.800	2.943	3.043	0.502
September	0.000	0.000	101.014	0.251	58.177	4.059	2.929	0.517
October	0.036	0.106	101.429	0.180	61.326	2.723	2.715	0.405
2021								
May	0.000	0.002	101.154	0.169	47.441	6.037	3.067	0.686
June	0.000	0.000	101.139	0.259	49.660	3.362	3.199	0.503
July	0.000	0.002	100.630	0.175	50.152	3.528	3.148	0.791
August	0.033	0.058	100.727	0.179	51.942	4.765	2.697	0.619
September	0.053	0.106	101.086	0.180	55.270	3.789	3.262	0.492
October	0.180	0.608	101.469	0.282	59.662	4.157	2.889	0.543

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Table (3): Fresh, dry and total yields (t ha^{-1}) of teosinte as affected by irrigation amount, nitrogen fertilizer rates and its interactions in 2020 and 2021 seasons.

Treatments	Fresh weight								Dry weight							
	2020				2021				2020				2021			
	Cut1	Cut2	Cut3	Total	Cut1	Cut2	Cut3	Total	Cut1	Cut2	Cut3	Total	Cut1	Cut2	Cut3	Total
Irrigation amount (a)																
Full+20%	9.57	12.62	11.26	33.45	9.57	13.86	12.38	35.81	1.440	2.360	1.810	5.610	1.471	2.188	2.233	5.893
Full irrigation	12.90	18.24	14.76	45.90	11.81	17.52	14.55	43.88	1.981	2.929	2.429	7.338	1.831	3.083	2.712	7.626
Full -20%	7.52	12.21	9.86	29.60	6.81	11.76	9.64	28.21	1.107	1.864	1.557	4.529	1.007	1.843	1.626	4.476
P value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
N- fertilizer rates (b) (kg N ha^{-1})																
140	7.02	12.24	9.93	29.19	6.31	11.81	9.90	28.02	1.036	1.881	1.574	4.490	0.936	1.879	1.681	4.495
210	10.02	14.55	12.31	36.88	9.55	13.83	12.43	35.81	1.500	2.279	2.000	5.779	1.448	2.271	2.244	5.963
280	12.95	18.67	13.62	45.24	12.31	17.52	14.26	44.10	1.995	2.976	2.250	7.221	1.926	2.940	2.648	7.514
P value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Interactions (a × b)																
a1xb1	6.98	11.71	8.50	27.19	5.40	11.55	9.86	26.81	1.033	1.783	1.348	4.164	0.790	1.752	1.671	4.214
a1xb2	9.19	13.90	11.62	34.71	10.29	13.21	12.74	36.24	1.376	2.198	1.886	5.460	1.567	2.105	2.300	5.971
a1xb3	12.57	19.33	13.64	45.55	13.00	16.76	14.60	44.36	1.910	3.093	2.252	7.255	2.057	2.707	2.733	7.498
a2xb1	9.43	14.07	12.48	35.98	9.38	14.76	9.81	33.95	1.402	2.217	2.050	5.669	1.426	2.495	2.079	6.000
a2xb2	13.02	17.17	15.79	45.98	11.98	17.29	14.88	44.14	1.969	2.738	2.619	7.326	1.838	3.012	2.812	7.662
a2xb3	16.26	23.50	15.98	55.74	14.05	20.52	17.05	51.62	2.571	3.812	2.714	9.098	2.231	3.674	3.243	9.148

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a3xb1	4.67	10.93	8.79	24.38	4.17	9.07	8.12	21.36	0.667	1.643	1.371	3.681	0.588	1.388	1.290	3.267
a3xb2	7.83	12.55	9.55	29.93	6.33	10.98	9.69	27.00	1.157	1.902	1.531	4.590	0.940	1.695	1.621	4.257
a3xb3	10.05	13.19	11.24	34.48	9.93	15.26	11.12	36.31	1.502	2.050	1.788	5.340	1.493	2.448	1.967	5.907
P value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

<0.05: significant at the 0.05 level

Table 4: Stem diameter (cm) and plant height (cm) of teosinte as affected by irrigation amount, nitrogen fertilizer rates and its interactions in 2020 and 2021 seasons.

Treatments	**Stem diameter (cm)**						**Plant height (cm)**					
	2020			**2021**			**2020**			**2021**		
	Cut 1	**Cut 2**	**Cut 3**	**Cut 1**	**Cut 2**	**Cut 3**	**Cut1**	**Cut2**	**Cut3**	**Cut1**	**Cut2**	**Cut3**
Irrigation amount (a)												
Full+20 %	0.90	1.48	1.23	1.13	1.49	1.34	128.44	153.11	132.11	129.00	151.37	138.00
Full irrigation	1.07	1.85	1.38	1.26	1.88	1.42	118.00	138.00	125.79	117.67	139.44	123.22
Full - 20%	0.80	1.33	1.07	0.96	1.40	1.27	103.44	117.56	106.89	103.67	115.00	106.67
P value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
N- fertilizer rates (b) (kg N ha^{-1})												
140	0.72	0.96	0.88	0.83	0.97	0.93	102.00	124.11	105.0	102.00	119.89	109.00
210	0.91	1.32	1.12	1.07	1.31	1.19	115.00	134.33	120.67	116.22	134.11	123.00
280	1.142	2.38	1.68	1.44	2.50	1.91	132.89	150.44	139.11	132.11	151.81	135.89
P value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Interactions (a × b)												
a1xb1	0.70	0.93	-	0.85	0.98	-	104.00	-	113.7	103.00	-	109.67

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a1xb2	0.90	1.28	-	0.99	1.36	-	116.00	-	121.0	117.00	-	121
a1xb3	1.11	2.22	-	1.54	2.14	-	134.00	-	142.67	133.00	-	139.00
a2xb1	0.85	1.053	-	0.95	1.10	-	109.00	--	109.30	114.33	-	125.00
a2xb2	0.97	1.69	-	1.18	1.60	-	127.00	-	132.00	125.00	-	138.33
a2xb3	1.38	2.81	-	1.65	2.93	-	149.00	-	155.00	147.67	-	150.66
a3xb1	0.60	0.88	-	0.69	0.83	-	92.67	-	92.00	88.67	-	92.33
a3xb2	0.85	0.99	-	1.05	0.97	-	102.00	-	109.00	106.67	-	109.67
a3xb3	0.93	2.12	-	1.15	2.4	-	115.67	-	119.67	115.66	-	118.00
P value	<0.05	<0.05	ns	<0.05	<0.05	ns	<0.05	ns	<0.05	<0.05	ns	<0.05

ns: not significant <0.05: significant at the 0.05 level

Table 5: Optimum and economic optimum nitrogen rate as affected by irrigation amount levels of teosinte.

Irrigation amount levels	Custom equation	R^2	*P* value	Std. Error of the Estimate	Optimum N rate to get maximum fresh yield (kg N fed^{-1})	Maximum fresh yield at optimum N rate (t fed^{-1})	Economic optimum N rate (kg N fed^{-1})	fresh yield at economic optimum N rate (t fed^{-1})
Full - 20%	$Y = 0 + 189.41X + (-0.231X^2)$	0.995	**	1.683	409.98	38.83	380.40	38.62
Full irrigation	$Y = 0 + 310.39X + (-0.430X^2)$	0.998	**	2.326	360.92	56.01	345.03	55.90

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Full +20%	$Y = 0 + 216.34X + (-0.204X^2)$	0.998	**	1.641	530.25	57.36	496.75	57.13

Table 6:Interactions between irrigation amount and nitrogen fertilizer rates on applied irrigation water (m3/fed) and actual evapotranspiration "ET_a" (m^3/fed) of teosinte in 2020 and 2021 seasons

Treatments	Applied irrigation water m^3 ha^{-1}						Actual evapotranspiration m^3 ha^{-1}					
	2020			2021			2020			2021		
	140	210	280	140	210	280	140	210	280	140	210	280
Full+20%	6464	7619	8476	6214	7429	8095	4371	4693	5488	4219	4719	5360
Full irrigation	5381	6369	7071	5190	6167	6738	4490	5305	5888	4329	4929	5600
Full -20%	4286	5119	5667	4167	5000	5405	4040	4312	5210	3850	4238	5288

Table 7: Interactions between irrigation amount and nitrogen fertilizer rates on water utilization efficiency (WU_tE), water use efficiency (WUE) and irrigation water application (Ea) of teosinte fresh yield in 2020 and 2021 seasons (Means over cuts)

Treatments	Water utilization efficiency (WU_tE)						Water use efficiency (WUE)						Irrigation water application (Ea)					
	2020			2021			2020			2021			2020			2021		
	140	210	280	140	210	280	140	210	280	140	210	280	140	210	280	140	210	280
Full+20%	4.20	4.55	5.36	4.31	4.67	5.47	6.2	7.4	8.3	6.3	7.6	8.2	0.67	0.61	0.64	0.67	0.63	0.66
Full irrigation	6.68	7.21	7.88	6.54	7.15	7.66	8.0	8.7	9.5	7.8	8.9	9.2	0.83	0.83	0.83	0.81	0.70	0.83
Full -20%	6.08	5.70	4.95	5.11	5.84	6.68	6.0	6.9	6.6	5.5	6.8	6.8	0.94	0.84	0.91	0.92	0.77	0.97

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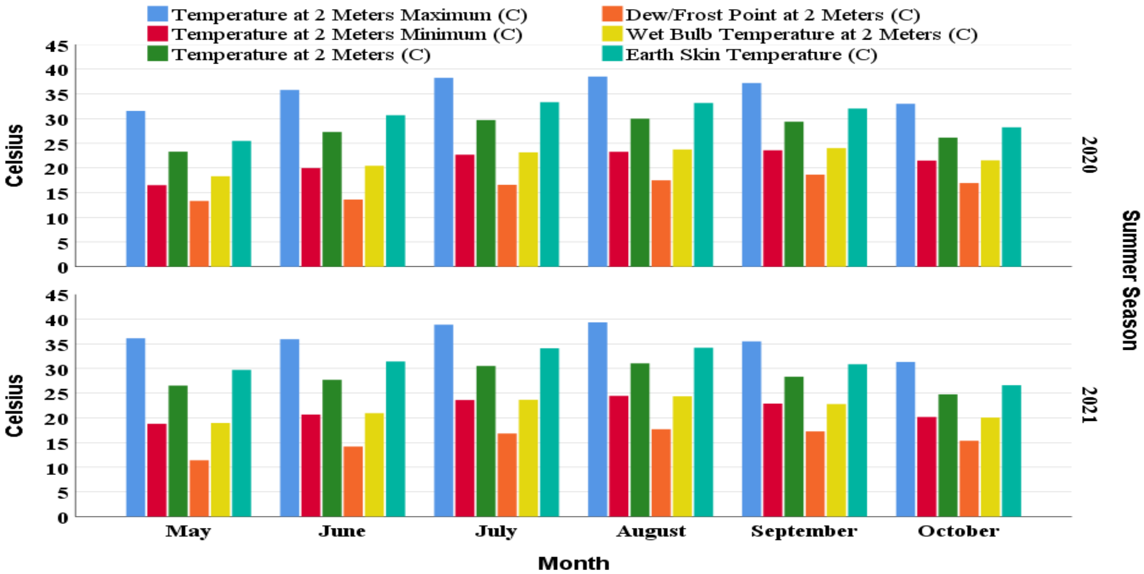

Fig. 1.Maximum, Minimum and main Temperature, Dew/Forest Point, Wet Bulb and Earth Skin Temperature (°C) of experimental site during summer seasons 2020 and 2021.

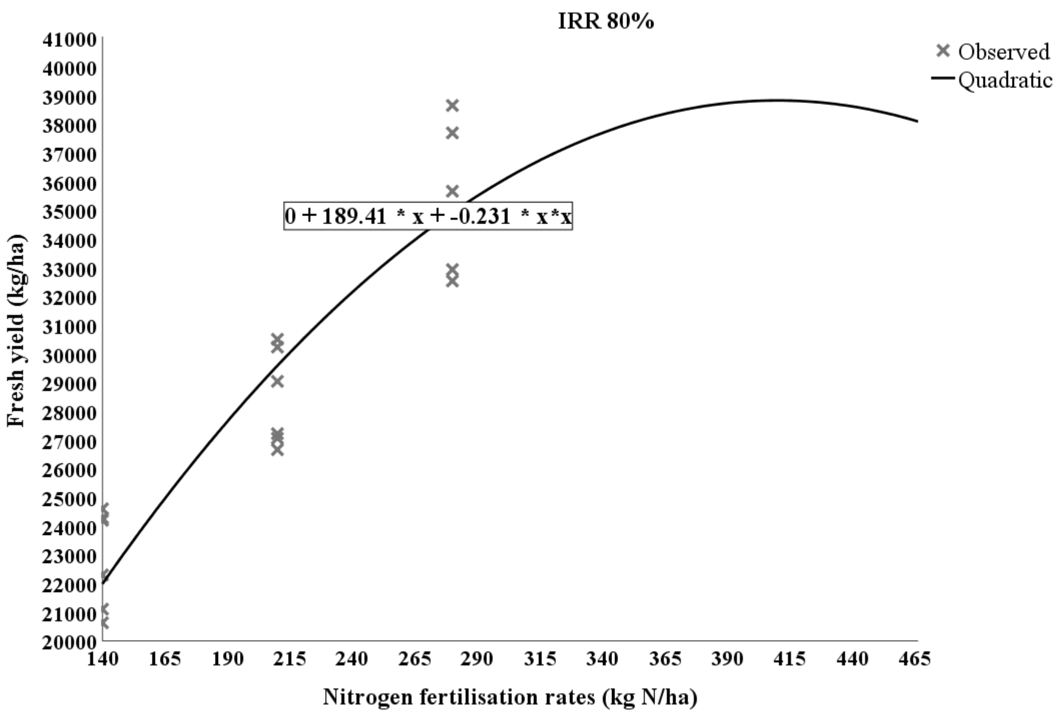

Figure (2): The relationship between fertilizer N application and teosinte fresh yield at 80% of recommended irrigation amount.

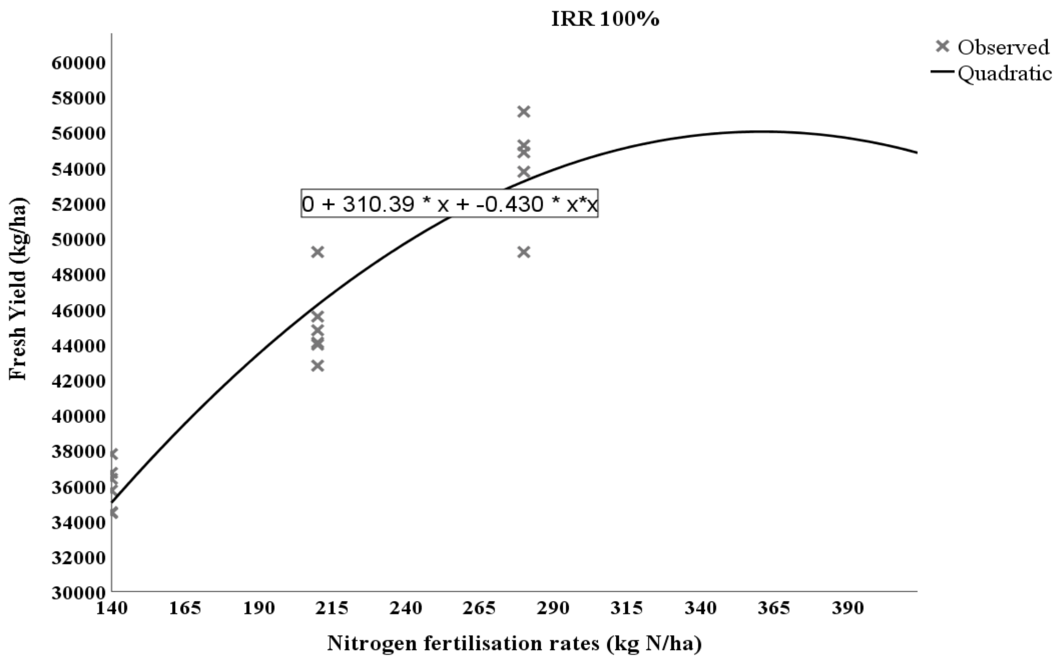

Figure (3): The relationship between fertilizer N application and teosinte fresh yield at 100% of recommended irrigation amount.

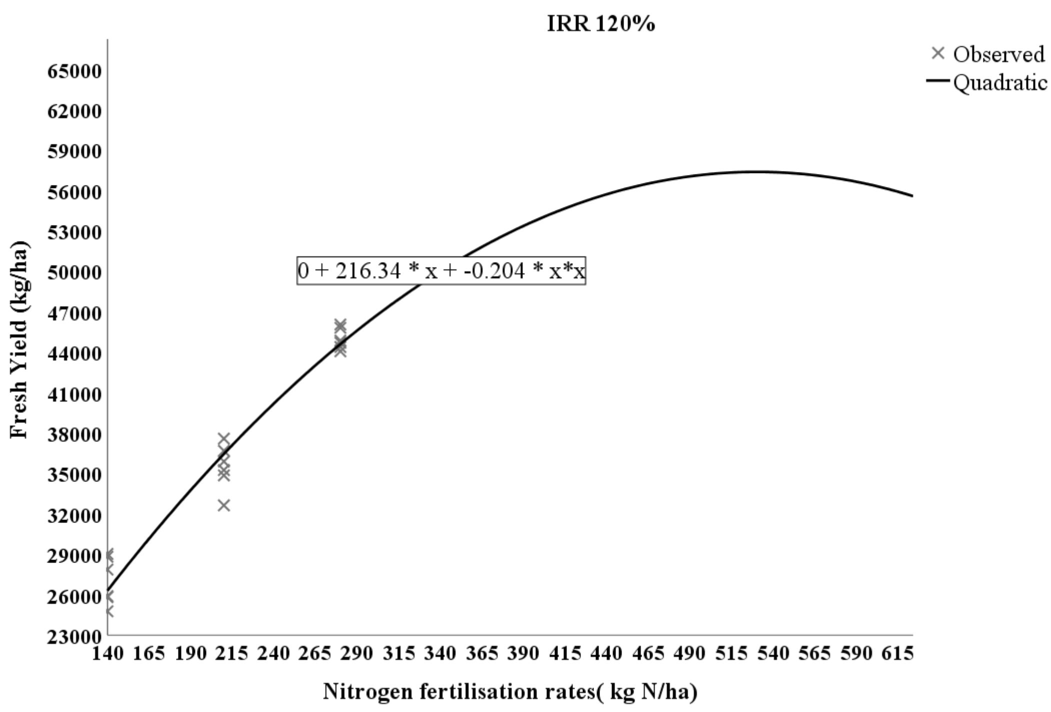

Figure (4): The relationship between fertilizer N application and teosinte fresh yield at 120% of recommended irrigation amount.