EVALUATION OF WATER USE EFFICIENCY (WUE) AND YIELD FOR MAIZE UNDER DIFFERENT NITROGEN AND WATER REGIMES

EVALUATION DE L'EFFICIENCE D'UTILISATION DE L'EAU ET DU RENDEMENT POUR LE MAIS SOUS DIFFERENTS REGIMES DE L'AZOTE ET DE L'EAU

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ABSTRACT

Productivity and resource-use efficiency are prime issues in maize (Zea mays L.), especially due to its high resource demand. Farmers having limited water often have to choose among options viz. fully irrigating a portion of the crop area, deficit-irrigation of a larger crop area, changing to less water requiring crops, or using more efficient irrigation systems. The objective of this study was to evaluate yield and water use efficiency (WUE) of maize, under different irrigation schedules and nitrogen application levels.

A field experiment was conducted using a randomized complete block design (RCBD) at Water Technology Center (WTC) farm, in IARI, New Delhi with five irrigation levels (viz. rainfed, two deficit irrigation levels (50 and 75%), full irrigation (100%) and over irrigation (125%) of soil moisture deficit (SMD) as main plots, in interaction with four nitrogen levels (viz. not fertilized, 75 , 150 and 225kg (N) ha^{-1} as sub plots with three replications. The maize hybrid BIO-9681 was planted with a population density of 66667 Plant per hectare on 22nd July 2009. Time and amount of irrigations were determined based on soil moisture deficit (SMD) with management allowed depletion (MAD) equal to 50% for the full irrigation treatments.

Nitrogen application rates affected grain and biomass yield and WUE, with significant differences between non-fertilized and the first two N treatments, but there was no significant difference between 150 and 225 kg (N) ha^{-1}. Also significant interaction of nitrogen and irrigation was observed for grain yield and WUE. The results of water regimes and nitrogen levels interaction showed that the highest yield and WUE of 6050 kg ha^{-1} and 12.1 kg ha^{-1}mm^{-1}, were obtained at 100% SMD and 225 kg (N) ha^{-1}, respectively. Application of

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254mm depth of irrigation water besides 255mm effective rainfall (ER) in full irrigation treatment increased yield by 39.9, 23.5% and 1.75% as compared to 50%, 75% and 125% irrigation levels, respectively.

Key words: *Irrigation; Nitrogen; Water use efficiency; Grain yield*

RESUME

La productivité et l'efficacité de l'utilisation des ressources sont des questions de choix dans le maïs (Zea mays L.), surtout en raison de sa demande de ressources élevée. Les agriculteurs ayant les ressources en eau limitées doivent souvent choisir parmi les options suivantes : irriguer complètement une partie de la superficie cultivée, irriguer en déficit une zone d'une grande culture, le passage à des cultures nécessitant moins d'eau, ou en utilisant des systèmes d'irrigation plus efficaces. L'objectif de cette étude était d'évaluer le rendement et l'efficacité d'utilisation de l'eau (WUE) de maïs, sous des différents programmes d'irrigation et des différents niveaux d'application d'azote.

Une expérience de terrain a été menée en utilisant un dispositif en blocs aléatoires complets (blocs de Fisher) à la ferme de Centre de Technologie d'eau (WTC), dans IARI, à New Delhi. Cet expérience avait cinq niveaux d'irrigation (notamment pluviale, l'irrigation déficitaire à deux niveaux (50 et 75%), l'irrigation complète (100%) et plus d'irrigation (125%) du déficit d'humidité du sol (SMD)) en tant que parcelles principales. Ils interagissent en présence de quatre niveaux d'azote (notamment pas fécondé, 75, 150 et 225 kg (N) ha^{-1} en sous-parcelles avec trois réplications. Le maïs hybride BIO-9681 a été planté avec une densité de population de 66667 plantes par hectare le 22 juillet 2009. Le temps de processus et la quantité d'irrigation ont été déterminés en fonction du déficit d'humidité du sol (SMD) en présence de l'appauvrissement de la gestion autorisés (MAD) égale à 50 % pour les traitements d'irrigation complet.

Les taux d'application d'azote ont affecté le rendement en grain, celui en biomasse et le WUE. Il y avait des différences significatives entre les non-fécondés et les deux premiers traitements de N, mais il n'y avait pas de différence significative entre 150 et 225 kg (N) ha^{-1}. Aussi une interaction significative d'azote et de l'irrigation a été observée pour le rendement en grain et WUE. Les résultats des programmes des eaux et des niveaux d'interaction de l'azote ont montré que le meilleur rendement et WUE de 6050 kg ha^{-1} et 12,1 kg ha^{-1} mm^{-1}, ont été obtenus à 100% SMD et 225 kg (N) ha^{-1}, respectivement. L'application de la profondeur 254 mm d'eau d'irrigation à part 255mm de pluie efficace (ER) dans le traitement de l'irrigation complet a augmenté le rendement de 39,9, 23,5% et de 1,75% aux niveaux de l'irrigation de 50%, 75% et de 125%, respectivement.

Mots clés : *Maïs, irrigation, azote, efficience de l'utilisation de l'eau, rendement en grain.*

1. INTRODUCTION

Water is becoming increasingly scarce worldwide and there is increased competition for water among different water user sectors and regions. In addition, the quality of water is often deteriorated, so that water resources become further constrained. Irrigated agricultural is therefore forced to find new approaches to meet the demands for technical feasibility, economic viability and social equilibrium (Pereira, 2006).

Maize (*Zea Mays L.*) has the highest average yield per hectare and is the third after wheat and rice in area and total production in the world. Maize is fairly sensitive to water stress (Bolanos, 1993, Pandey *et al*., 2000; Cakir, 2004). Thus, when water is limitted it is difficult to impelement irrigation management strategies without incurring yield losses (Farre and Faci, 2006).

Manish Kumar *et al*. (2001) reported that scheduling of irrigation at 1.0 IW/CPE ratio gave higher grain yield (34.38 q ha^{-1}) of winter maize over 0.7 ratios (28.78 q ha^{-1}).

Sunder Singh (2001) observed that scheduling irrigation at 1.0 IW/CPE ratio gave higher plant height (23.0 cm), dry matter production (13500 kg ha^{-1}) over IW/CPE ratio of 0.5 and 0.75 in baby corn. Yield attributes like number of cob $plant^{-1}$ was maximum in 1.0 IW/CPE ratio (3.78) over 0.5 and 0.75 ratio (2.99 and 3.67, respectively) and young cob yield and stover yield was also maximum in IW/CPE ratio of 1.0 (50.74 and 27.97 q ha^{-1}, respectively) over others in sandy soil during summer at TNAU.

Okten and Simsek (2004) at Turkey reported maximum grain yield of dent corn at application of 10% deficit irrigation and 4-day irrigation interval, while minimum yield was at application of 30% deficit irrigation and 8-day irrigation interval. Yield characteristics were affected negatively by 30% deficit irrigation and 8-day irrigation interval in clay soil under arid condition. The present study was undertaken to examine the response of maize to irrigation schedules and nitrogen rates under semi arid condition.

2. MATERIALS AND METHODS

2.1. Study site, soil and climate data

A field experiment was conducted during the year 2009 at Water Technology Center (WTC) research farm of Indian Agricultural research Institute (IARI), New Delhi. The experimental area in IARI farm is enclosed between 37′ 22″ - 28° 39′ N latitude and 77° 8′ 45″ - 77° 10′ 24″ E longitude with an average elevation of 230 m amsl. Daily meteorological data, including maximum and minimum temperature and relative humidity, sunshine, wind speed at 2 m above ground and rainfall, were obtained directly from weather station located about 150 m away from the experimental plots (Table 1). The experiment was undertaken in a 1 ha block of WTC farm having surface irrigation facility. The soil physical properties and chemical analyses of the irrigation water are presented in Tables 2 and 3, respectively.

Table 1: Weather parameters during entire crop growing season in 2009

Month	Rainfall (mm)	Temperature Maximum	Temperature Minimum	RH	
				Maximum	Minimum
July	110.4	35.2	26.6	77.8	62.1
Aug	188.6	34.7	26.1	76.7	62.0
Sep	202	33.2	23.3	86.3	57.3
Oct	0	32.9	16.9	86.1	59.1
Seasonal	501				

Table 2: Soil physical properties of experimental field

Soil depth (cm)	Texture	Sand (%)	Silt (%)	Clay (%)	Bd (gm/cc)	Fc (%)	PWP (%)	Ks (cm d^{-1})	θs (%)
0-15	Loam	48	21	30	1.41	18.3	6.8	380	41
15-30	Sandy-loam	53	19	28	1.43	19.1	6.9	460	40
30-45	Loam	44	23	33	1.39	20.7	8.7	364	44
45-75	Loam	39	25	36	1.37	21.6	9.8	250	47
75-105	Clay. L	38	27	34	1.36	23.0	10.9	180	49
Methods:	Hydrometer		Core sampler Pressure plate						
Permeameter									

† Bd: Bulk density, Ks: saturated hydraulic conductivity, θs : soil water content at saturation, Fc: field capacity, PWP: permanent wilting point

Table 3: Chemical analysis for irrigation water

EC(ds/m)	PH	Anions meq/l			Cations meq/l			
		Cl^{-1}	HCO^{-3}	CO^{-3}	K^{+}	Mg^{2+}	Na^{+}	Ca^{2+}
1.4	8.05	12.5	1.8	---	0.72	3.21	14.6	8.6

2.2. Experimental design

The experiment was laid in randomized complete block design (RCBD) having five irrigation levels viz. rainfed (or non-irrigated: W1) and four irrigations at 50 (W2), 75 (W3), 100 (W4) and 125 (W5) per cent of soil moisture deficit (SMD) as main plots and four nitrogen levels viz. not fertilized (N1), 75 (N2), 150 (N3) and 225 (N4) kg N ha^{-1} as sub plots with three replication. There were five furrows in each plot of 3.5 × 3.75 m size and the replications were separated by 2.5 m. The furrows were 75 cm apart with plant spacing of 20cm in each furrow.

2.3. Cultural practices

The seed bed was prepared by deep plowing, disking and loosening. The field was fertilized at plowing with superphosphate (15.5%) and potassium sulfate (48%) at the equivalent rate of 100 kg P ha^{-1} and 100kg K ha^{-1}, respectively. The maize hybrid BIO-9681 was planted manually, two seeds per hole at 0.2 m seed spacing and with 0.75m row spacing at an average in row density of 6.7 seeds m^{-2}. Maize was planted on 22nd July and harvested on 27th October 2009. Furrow method of irrigation, commonly used for row crops in the region, was used. The N fertilizer was applied with three split doses with one-third given as basal, one-third at 21 days after sowing (DAS) and the remaining at 42 DAS of the crop. In order to measure yield and yield components, plants of three middle rows of each plot representing 7.8 m^2 area were harvested at the physiological maturity stage. Grain yield was measured as weight of harvested grain in each plot and adjusted to 13% moisture, then converted to ton per hectare for each treatment. Total biomass yield was determined as the total above ground biological yield (grain and all other parts).

2.4. Irrigation scheduling

The quantity of irrigation water for each treatment was calculated based on the soil moisture content before irrigation and root zone depth of the plant using the relation:

$$SMD = (\theta_{FC} - \theta_i)^* DRZ^* Bd^*f$$

Where:

SMD: Soil moisture deficit (mm), θ_{FC} : Soil water content at field capacity, θ_i : Soil water content before irrigation (weight percent), D_{RZ}: Depth of root development (mm), B_d: Bulk density of the particular soil layer (g cm^{-3}), f: Coefficient of each treatment.

Time of irrigations in full irrigation treatment was when soil moisture in the root zone approached 50% of total available water (TAW), refilling soil moisture in the root zone to field capacity (FC). In the deficit irrigation treatments water was applied on the same day as the fully irrigated plot, but the amount of irrigations depths were reduced to 50 and 75% for deficit irrigation and increased to 125% for over irrigation of the full irrigation.

2.5. Crop sensitivity to water stress

The effect of water stress on yield during the growing season was calculated as follows (Doorenbos and Kassam, 1979):

$$(1 - \frac{Ya}{Ym}) = \mathrm{ky}(1 - \frac{ETa}{ETm}) \quad (1)$$

Where:

Y_a: actual harvested yield (kg ha^{-1}), Y_m: maximum harvested yield (kg ha^{-1}), Ky: yield reponse factor , ET_a: actual evapotranspiration (mm) , ET_m: actual evapotranspiration (mm) , $(1-Y_a/Y_m)$: relative yield decrease and $(1-ET_a/ET_m)$: relative evapotranpiration deficit.

2.6. Soil water and evapotranspiration measurements

The soil water content was measured using the gravimetric soil samples by soil auger. Measurements were regularly made at 15 cm increments to a depth of 1.05 m at 24 hour before and 48 hour after irrigation. Soil samples oven-dried at 105°C and the gravimetric soil water contents (%) were measured and volumetric soil water contents (cm^{-3} cm^{-3}) were calculated.

Actual crop evapotranspiration of maize (ETc, mm d^{-1}) was estimated by using the following equation (Jensen, 1973):

$$ETc = \frac{(I+P-D)+\sum_{i=1}^{n}(\theta 1-\theta 2)\Delta S}{\Delta t} \quad (2)$$

Where: I, P and D are irrigation, precipitation and deep percolation from the bottom of root zone (mm), n the number of layers, ΔS is the thickness of each soil layer (mm), θ_1 and θ_2 are the volumetric soil water content (cm^{-3} cm^{-3}) 24 hr after and 24 hr before next irrigation, and Δt is the time interval between two consecutive measurement (day).

Moisture content in the 0-105 cm soil profile was measured gravimetrically before irrigations. Since furrows were closed was no observed runoff during the experiment and the water table was at 4 m depth, capillary flow to the root-zone and runoff flow were assumed to be negligible in the calculation of ET. Drainage below root zone, after a number of soil-water content measurements, was considered as negligible. So the above equation was reduced to:

$$ET = I + P \pm \Delta s \quad (3)$$

Field water balance is commonly used to measure total actual water use or crop evapotranspiration (ETa) when lysimeter facilities are not available (Prihar and Sandhu, 1987; BandyoPadhyay and Mallick, 2003,Farahani, 2009).

2.7. Crop Water use efficiency (WUE)

Crop water use efficiency (WUE), or yield per unit of water used, can be improved through irrigation management and methods, including deficit irrigation (irrigating less than is required for maximum yields) and supplemental irrigation (irrigating to supplement precipitation so as to avoid crop failure or severe yield decline). Although field experiments are too costly to address all the scenarios, computer models of crop growth and yield may fill in the gaps if the models are shown to be accurate WUE predictors. The WUE is calculated as follows (Howell *et al*., 1995):

$$WUE = \frac{Y}{ET} \quad (4)$$

Where: Y: grain yield (kg ha^{-1}), ET: crop evapotranspiration (mm)

3. RESULTS AND DISCUSSION

Analysis of variance for the design was carried out using MSTATC software (Table 4). When the treatment effects were found significant, mean differences were tested using Duncan's Multiple Range Test (DMRT) at 5% or 1% level of probability.

Table 4. Analysis of variance (ANOVA) for yieldand water use efficiency (WUE)

Source	df	Mean Square		
		Yield	Biomass	WUE
Reps.	2	13552	27221.33	0.1353
Irrigation (I)	4	12127220**	58615870**	9.817 **
Error (I)	8	24567.33	160339.50	0.189
CV (%)		4.65	3.50	4.85
Nitrogen (N)	3	6909488**	92892930 **	50.59**
I*N	12	450672 **	3257768**	1.742 *
Error (N)	16	20531.25	99276	0.153
CV (%)		4.25	2.75	4.36

*, ** Significant in 0.05 and 0.01 probability levels and NS, not significant, respectively.
†, I*N: Interaction effect of water and nitrogen.

Table 5: Comparison of yield and biomass of two years 2009

Treatment	level	Yield (Kg ha^{-1})	Biomass (Kg ha^{-1})	WUE (Kg mm^{-1} ha^{-1})
Irrigation	W1	2004.1	8195.1	8.02
	W2	3116.2	11168.9	8.78
	W3	3535.9	12105.9	8.67
	W4	4813.9	14354.3	10.46
	W5	5120.3	14654.8	9.67
	CD(P=0.05)	180.8	461.9	0.50
Nitrogen	N1	2592.2	8682.2	6.9
	N2	3401.7	11439.3	9.03
	N3	4108.7	14246.6	11.0
	N4	4780	14758.6	10.7
	CD (P=0.05)	123.9	336.5	0.34

Grain yield:

The results showed that maize grain yield were significantly affected at (P<0.01%) and (P<0.05) level by varying levels of irrigation and nitrogen treatments during the experiment.

Irrigation treatments resulted in differences in grain yield under different fertilizer levels (Fig.1). Increased water application resulted in a relatively higher yield, since water deficit was main yield-limiting factor in 2009. The maximum and minimum yield was obtained at full irrigation (W_4) in interaction with 225 kg ha^{-1} (N_4) and rainfed conditions in interaction with non- fertilized (N_1) at the rate of 6050 and 1430 kg ha^{-1}, respectively.

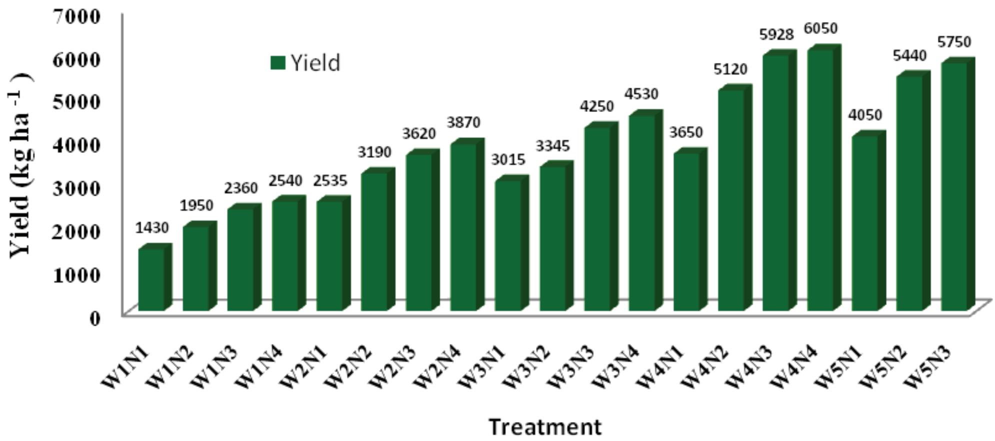

Fig.1. Interaction effect of different nitrogen and water regimes on maize

The relations between seasonal crop water use, grain yield and biomass were evaluated for each year (Fig. 2). These relationships were linear for the experimental year. A linear relationship between crop water use and yield and biomass for maize has been reported by other researchers also (Payero *et al*., 2006; Dagdelen *et al*., 2006; Cetin, 1996). The ANOVA presented in Table 5, shows that during two years of the study, there were significant effects due to primary factors and their interactions.

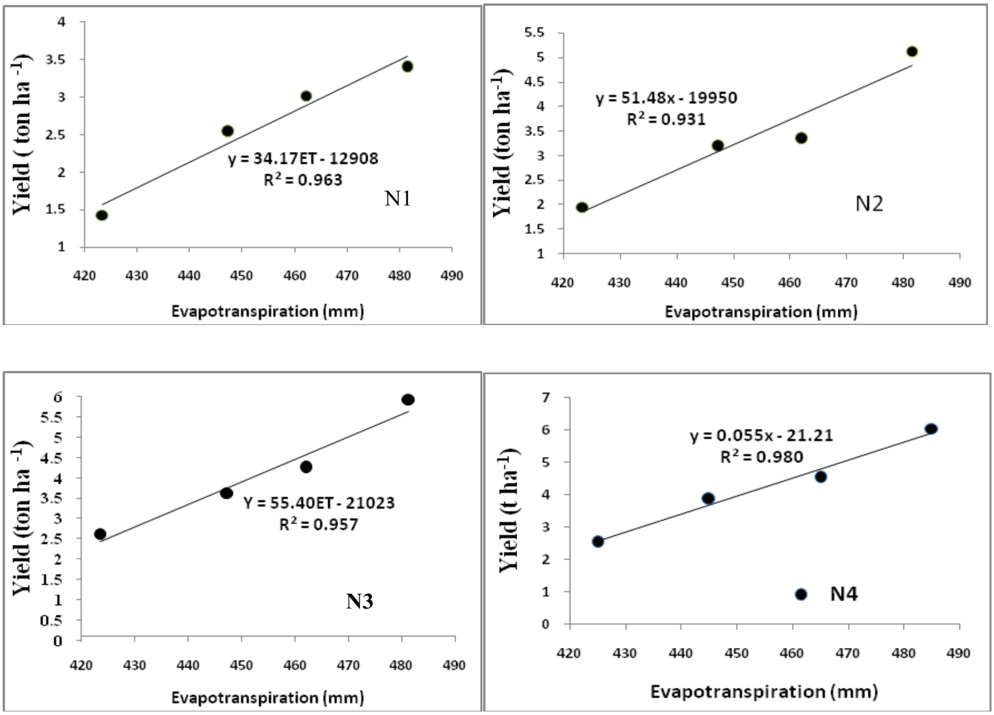

Fig.2 - Relationship between grain yield and seasonal crop water use under different N levels

Water use efficiency and irrigation water use efficiency:

WUE, ranged from 5.7 to 12.1 kg ha^{-1}mm^{-1} in 2009. It was the highest for full irrigation (W_4) under 225 kg N ha^{-1} (N4) treatment, and the lowest for rainfed (W_1) treatment under non-fertilized (N1). Variation of WUE under different irrigation water and nitrogen levels has been shown in Fig.3.

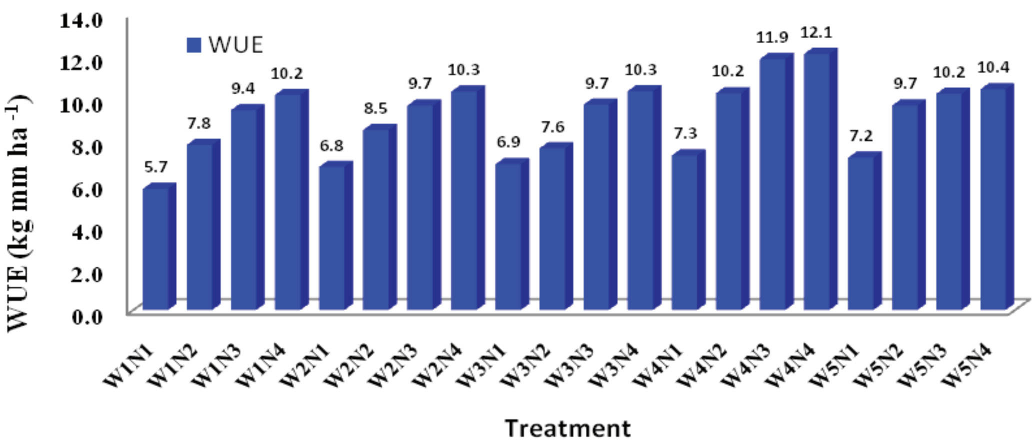

Fig.3. Water use efficiency (WUE) of maize under different irrigation water and nitrogen levels

Relative yield response factor (Ky):

The yield response factor (K_y) is shown in Fig. 4. The yield response factor (K_y) values of maize to water deficit for entire growing season under recommended fertilizer, (N_3), were 1.3 in 2009. Generally, the K_y value obtained in this study was consistent with those reported by Gencoglan (1996) as 1.23 and by Cakir (2004) as 1.29. Some differences could be explained by the high relative humidity and rainfall. On the other hand, Igbadun et al. (2006) reported the K_y value to be 1.9. The high value for K_y obtained in their study is an indication of severe moisture stresses or low resistance to moisture stress. It implies that the rate of relative yield decrease resulting from moisture stress is proportionally higher than the relative evapotranspiration deficit.

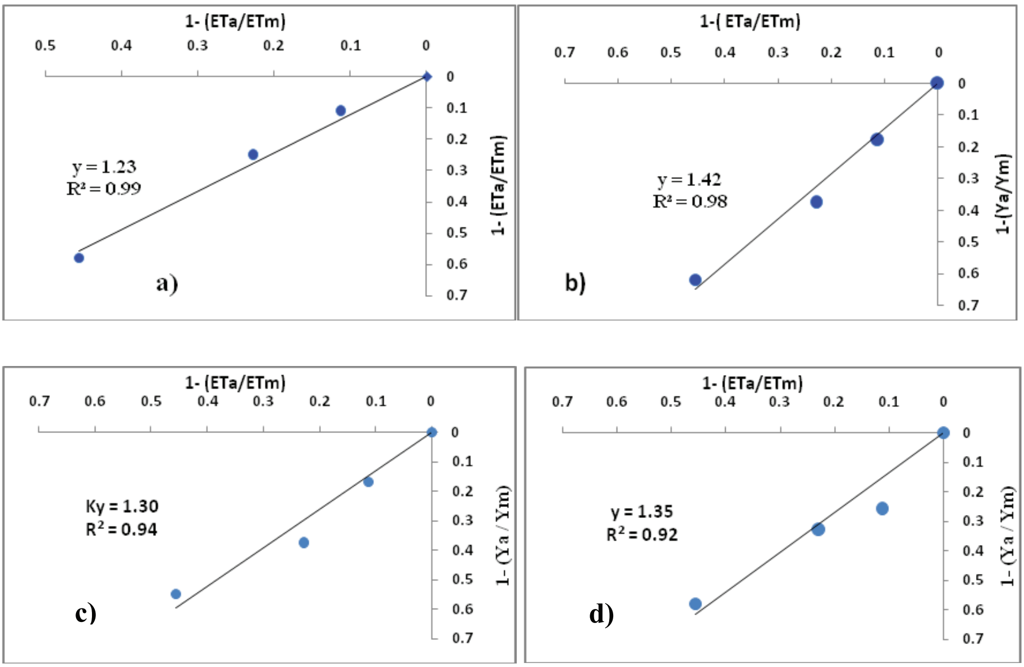

Fig.4. Yield response factor, K_y for maize under different nitrogen levels; N_1 (a), N_2 (b), N_3(c) and N_4 (d) in 2009

4. CONCLUSIONS

It was concluded that maize grain yield and water use efficiency (WUE) were significantly affected by varying levels of irrigation and nitrogen application during the crop growth period. It was also observed that there was significant effect of the irrigation water levels on grain and biomass yield at 99% probability level. Nitrogen levels also resulted in significant variation in grain yield at 99% probability level. However, the difference in grain yield was non-significant for W4 treatment in interaction with nitrogen rate of 150 (N3) and 225kg N ha^{-1} (N4) with yields of 5928 and 6050 kg ha^{-1}, respectively. Maximum grain yield of 6050 kg ha^{-1} was obtained at full irrigation (W4) with 225 kg N ha^{-1} (N4). Maximum WUE was obtained for W4N4 treatment at the rate of 12.1 kg mm ha^{-1}.The results also showed that with increasing irrigation water depth beyond of full irrigation (W4) not only grain yield was decreased, but also water use efficiency was decreased for all nitrogen levels.

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