THE INTERACTIVE EFFECTS OF WATER MAGNETIC TREATMENT AND DEFICIT IRRIGATION ON PLANT PRODUCTIVITY AND WATER USE EFFICIENCY OF CORN (ZEA MAYS L.)*

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ABSTRACT

A maize (*Zea mays L.*) field experiment was conducted in *Sulaimania* Governorate, *Iraq* to study the influence of water magnetism under full and limited irrigation schemes on actual evapotranspiration ET_a, growth and yield of corn. Drip Irrigation system was used to apply water for all treatments to bring the soil moisture content of the 0-90 cm layer up to the field capacity. Three different irrigation treatments (I_0, I_1 and I_2) were applied depending on soil water depletion replenishments. Symbols I_0, I_1 and I_2 refer to treatments receiving 100%, 75% and 50% soil moisture depletion successively which were applied right after the emergency stage. The results showed that the growth and productivity of corn were increased by water magnetism under both full and limited irrigation. Both of water use efficiency WUE and irrigation water use efficiency IWUE increased when irrigation water was magnetized particularly under water deficit condition. The growth and productivity parameters of corn were directly proportional to actual ET starting from the minimum values of ET_a up to maximum ET (ET_m) level. Maximum WUE and IWUE were obtained when ET_a/ET_m ratio were between 0.65-0.85. Average values of crop ET (ET_c) calculated by Blaney-Criddle and Hargreaves equation can be used to estimate the amount of applied irrigation water because of the closeness of ET_c values from ET_a values. Crop response factor for corn decreased when magnetized water was used for irrigation. The best magnetic flux density was 50-100 mT to give the best response for corn crop. Most measured physical and chemical properties of water were slightly affected by magnetism.

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التاثيرات المتداخلة لمغنطة الماء والري الناقص في انتاجية وكفاءة استخدام المياه لمحصول الذرة الصفراء

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المستخلص

اجريت تجربة حقلية على محصول الذرة الصفراء في محافظة السليمانية لدراسة تاثير مغنطة الماء تحت نظامي الري الكامل والناقص في التبخر نتح الفعلي ونمو وحاصل الذرة الصفراء. استخدم نظام الري بالتنقيط لاضافة الماء لكافة معاملات التجربة وذلك لايصال رطوبة التربة للطبقة 0 –90 سم لحدود السعة الحقلية. اضيفت ثلاث معاملات ري مختلفةI1,I0) و I2 (وذلك طبقاً لاستنفاذ رطوبة التربة. تشير الرموزI0 و I1 ,I2 الى المعاملات التي استلمت 100% و75% و50% من الماء المستنفذ على الترتيب والتي طبقت مباشرة بعد مرحلة بزوغ البادرات.

بينت النتائج زيادة كل من نمو وانتاجية محصول الذرة الصفراء بفضل مغنطة المياه تحت كلا نوعي الري (الكامل والناقص). ان كلا من كفاءة استخدام الماء WUE وكفاءة استخدام ماء الري IWUE زادت بفعل مغنطة ماء الري وخصوصاً تحت ظروق الري الناقص. ارتبطت معايير النمو والانتاجية للمحصول بصورة مباشرة مع التبخر نتح الفعلي (ETa) ابتداءاً من القيم الدنيا لقيم ETa وحتى اعلى قيمه له (ETm) . استحصلت القيم العظمى لكل منWUE و IWUE عندما تراوحت نسبة ETa / ETm بين 0.65 – 0.85. يمكن استخدام متوسطات قيم التبخر نتح المحصولي (ETc) المحسوبة باستخدام معادلتي Blaney – Criddle و Hargreaves لتخمين كمية ماء الري المضاف وذلك لتقارب هذه القيم من قيم ETa. انخفض عامل استجابة محصول الذرة الصفراء Ky عند استخدام الماء الممغنط في الري. ان افضل شدة تدفق مغناطيسية كانت 50 – 100 ملي تيسلا وذلك لاعطاء افضل استجابة لمحصول الذرة الصفراء. يشار الى ان اغلب الصفات الفيزيائية والكيميائية للماء تاثرت قليلاً بمغنطته.

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*جزء من اطروحة دكتوراه للباحث الثاني.

Introduction

Socioeconomic pressures for increasing agricultural production have led the farmers to apply water, fertilizers, pesticides and herbicides in excess of crop needs lead to leaching of water and nutrients below the root zone. *Part of PhD dissertation for the second author

An increasing number of countries are concerned by two major problems: reduction of high-quality water resources allocated to agriculture as well as increasing groundwater contamination, which apparently stems from agricultural activities (1,6). The purposes of the modern irrigation system techniques (including magnetic irrigation water treatment) are to increase the water use efficiency for production systems to save water and limit leaching to reduce groundwater pollution hazards. Groundwater is an important part of the natural resources which can be clearly realized in areas where supplementary irrigation is mostly required such as the Kurdistan region of Iraq.

Magnetic treatment of irrigation water is an acknowledged technique for achieving high water use efficiencies due to its effect on some physical and chemical properties of water and soil (13). These changes result in an increased ability of soil to get rid of salts and consequently better assimilation of nutrients and fertilizers in plants during the vegetative period. Moreover, when the plant is watered using hard and non-magnetized water, a white coat of calcium bicarbonate and carbonate is formed on the soil surface, some of which is washed away by water penetrating into the soil and deposits on the plant roots. Then the plant starts to suffocate and additional roots are formed in order to survive resulting in a decrease of plants normal growth.

Magnetizing methods among different physical and chemical methods of natural water treatments attract a special attention due to their ecological purity, safety, and simplicity. Magnetically treated water (MTW) is the water that is subjected to treatment by a magnetic field. For irrigation purposes, this means that the water which has been passed through an apparatus containing a permanent magnet. The use of *MTW* is common in various branches of industry as a precaution against accumulation of scale in the water supply system, cooling towers, thermal and solar heating installations (12).

Increasing the water use efficiency means reducing irrigation requirements (IR_R) for crop production which can be define as the amount of water in addition to rainfall that must be applied to meet a crop's evapotranspiration needs without significant reduction in yield. Evapotranspiration and rainfall are two main climatic elements to be considered in evaluating suitability of water for irrigation (18).

Since Iraqi Kurdistan region located in a semi-arid region in which the shortage of water resources exists especially during the summer months starting mostly from the beginning of June until the end of September. Design philosophy of irrigation system is required in order to meet the peak evapotranspiration of the crops needed to obtain higher yields.

Corn (maize) is a very responsive crop to irrigation both positively and negatively when the amount of water is sufficient or insufficient, respectively (11). Maize is an important food crop in the world which has been useful as a food, feed, construction material, fuel and medicinal or decorative plant. With the industrial development, it increasingly became an industrial raw material for the production of starch, gluten, oil, flour, alcohol and lignocelluloses for further processing into a whole range of products and byproducts. (1).

The objectives of the work reported here were to:

-Evaluate the impact of different magnetic levels on some physical and chemical properties of irrigation water.

-Study the effects of magnetizing water on the growth and production parameters of corn crop.

Study the effects of different levels of limited irrigation on corn growth and production.

-Find out the influence of magnetizing the irrigation water to reduce the influence of its shortage and hence its influence on growth and production of corn.

-Evaluate some methods of determining corn evapotranspiration under the study region condition.

Materials and Methods

A corn field experiment was conducted in Sulaimania, Iraq. The soil texture was silty clay loam and classified as Fine Loamy Siliceous Hyperthermic Typic Torrifluvents. The climate in the region is classified as semi-arid with total annual precipitation of 500 mm. The climatic data during the growing season (June-October, 2007) was taken and the meteorological data were used to calculate reference evapotraspiration (ET_o) in mm day^{-1} for *Sulaimnyia* from 1973 to 2007 by using *modified Blaney–Criddle* and *Hargreaves* equations, respectively. Then monthly ET_c was calculated using the general ET_c equation:

$$\boldsymbol{ET_c = k_c * ET_o} \quad \text{………………} (1)$$

Where: ET_c = calculated crop evapotranspiraion (mm day^{-1}), k_c = Crop coefficient, and ET_o = Reference evapotraspiration (mm day^{-1}).

Drip Irrigation system was used to apply water for all treatments in year 2007 to bring the soil moisture content of the 0-90 cm depth up to the field capacity. Three different irrigation treatments I_0, I_1 and I_2 were applied to the 90 cm root depth depending on soil water depletion replenishments. Symbols I_0, I_1 and I_2 refer to treatments receiving 100%, 75% and 50% soil moisture depletion successively which were applied right after the emergency stage. As the activity of magnetic water lasts only 72 hours (10) the irrigation period should be at shorter intervals and small amounts of water must be added compared to the conventional irrigation. The variation of soil water content was monitored by using tensiometers and Halogen-gravimetric method at 30 cm increments to a depth of 90 cm twice a week during the growing season.

Actual evapotranspiration (ET_a) was calculated by applying the water balance equation to the upper 90 cm soil layer using the following equation (7):

$$ET_a = P + I - D - R_f \pm \Delta W \quad \text{……………} (2)$$

Where: P the amount of precipitation mm, I irrigation water applied mm, D deep percolation mm, and ΔW variation in water content of the soil profile mm. Deep percolation D and surface runoff R_f were assumed to be negligible because the amount of irrigation water was below field capacity as a result of using drip irrigation and deficit irrigation. The drip lines were installed on the soil surface 70 cm apart with emitters at 25 cm using a drip line for each row of the maize plants and the flow rate of each emitter was 1.8 L hr^{-1}, with uniformity distribution of 95%.

The magnetic water treatments were administrated by passing the irrigation water through three different magnetic flux densities: 50, 100, 200 mT (mT = milli Tesla, 1Tesla = 10000 Gauss) in addition to the control treatment. A local magnetism device consisted of three pairs of special magnets spaced apart and mounted parallel to the length of water-carrying copper pipe. Similar poles marked with a simple dry magnetic pocket compass were arranged next and opposite to each other on the first and second side of the pipe, respectively . Each pair magnets and a tape that holds them, forms a unit which clamps individually around the pipe (16). The water flow was vertical upwards according to Lin and Yotvat (1991) with velocity of 2 m s^{-1} (2). Treatments consist of four levels of magnetic flux density measured by Tesla meter model 5070 and they were as the follows: B_o without magnetic treatment (control), B_1=

50mT*, B_2= 100mT and B_3= 200mT; the magnetic treatments apparatus were set up close to the water outlet of the main line.

Water use efficiency (WUE) and irrigation water use efficiency (IWUE) were calculated from the following two equations.

$WUE = Y_a/ET_a$ ………… (3) (19).

$IWUE = Y_a/I$ …………… (4) (8,17).

Where: Y_a: actual yield (kg m^{-2}) , ET_a : actual crop evapotranspiration ($m^{-3}m^{-2}$), and I: irrigation water applied ($m^{-3}m^{-2}$).

The yield response factor was determined using the Stewart et al. (1977) model in which dimensionless parameters in relative yield reduction and relative water consumption are used (4):

$$\left(1-\frac{Y_a}{Y_m}\right)=k_y\left(1-\frac{ET_a}{ET_m}\right) \text{ ………………………… (5)}$$

where Y_a is actual yield (kg m^{-2}), Y_m maximum yield (kg m^{-2}), Y_a/Y_m relative yield, 1-(Y_a/Y_m) decrease in relative yield, ET_a actual crop water consumption ($m^{-3}m^{-2}$), ET_m is maximum crop water consumption ($m^{-3}m^{-2}$), ET_a/ET_m is relative crop water consumption, 1-(ET_a/ET_m) is decrease in relative crop water consumption, k_y is yield response factor defined as decrease in yield per unit decrease in *ET*.

Physical and chemical properties of the soil studied were determined following the procedures outlined by Klute et al.(1986) and Page et al.(1982), respectively (Table,1).

The water source used for irrigation was ground well. Water samples for each magnetizing treatment (Bo, B1, B2 and B3) were taken from drip irrigation laterals during July for chemical and physical analyses.

Pant growth parameters used in this study were: plant height, total leaf number TLN, total leaf area, leaf area index (LAI), stem radius. Where:

Leaf area = 0.75 (length x width) …...(6) (15)

and,

$$LAI = \frac{leaf\ area\ cm^2}{area\ occupied\ by\ plant(s) cm^2} \text{ … … (7)}$$

(3)

Corn yield characteristics used were: grain yield, total dry matter, total aboveground dry matter, 1000-grain mass.

Water use efficiency and (WUE) and irrigation water use efficiency (IWUE) for grain, dry matter, and aboveground dry matter were determined using Eqs. (3) and (4) for all irrigation levels and magnetic treatments. Crop response factor (k_y) using Eq.(5) was also calculated for all treatments.

Results and Discussion

The change in soil water storage on weight basis for I_0 treatment ranged from 22.8 to 28.8%. The least soil moisture profile was observed for I_2 treatment on the harvesting time. The range of soil moisture profile on weight basis was 17.4-28.8%. For I_0, I_1 and I_2 treatments the cumulative actual evapotranspiration (ET_a), depth of irrigation and water use were: 655, 550 and 426 mm; 733, 588 and 443mm; 821, 676 and 531mm, respectively (Table 2). These parameters were measured from the beginning of emergence stage until harvesting. Actual evapotranspiration was linearly related to irrigation water applied and/or water used which indicates that no irrigation excess was used for the experiment. Figure (1) shows the depth of irrigation applied for the three irrigation treatments used.

Table 1: Some physical and chemical properties of Kostaycham soil.

Characteristics	Units	Soil depths cm			
		0-30	**30-60**	**60-90**	**90-120**
Sand	g kg^{-1}	187.3	241.0	348.8	298.2
Silt	g kg^{-1}	476.5	511.2	418.8	454.8
Clay	g kg^{-1}	336.2	247.8	232.4	247.0
Textural class	------	SiCL	SiL	L	L
Water content at -300 kPa	g kg^{-1}	305	286	272	277
Water content at -1500 kPa	g kg^{-1}	162	142	128	136
Available water content	g kg^{-1}	143	144	144	141
Bulk density	Mg m^{-3}	1.29	1.35	1.38	1.36
ECe at 25°C	dS m^{-1}	0.47	0.40	0.35	0.32
pH	------	7.84	7.71	7.73	7.73
CEC	$cmole_c$ kg^{-1}	37.22	28.47	24.39	25.81
$CaCO_3$	g kg^{-1}	383.3	444.5	503.5	506.5
Organic matter	g kg^{-1}	20.5	13.1	6.5	5.7
Calcium Ca^{2+}	$mmole_c$ L^{-1}	6.37	5.51	4.15	4.78
Magnesium Mg^{2+}	$mmole_c$ L^{-1}	0.51	0.42	0.66	0.42
Potassium K^+	$mmole_c$ L^{-1}	0.21	0.06	0.06	0.05
Sodium Na^+	$mmole_c$ L^{-1}	0.90	0.79	0.69	0.76
Carbonate CO_3^{2-}	$mmole_c$ L^{-1}	0.00	0.00	0.00	0.00
Bicarbonate HCO_3^-	$mmole_c$ L^{-1}	6.26	5.02	3.90	4.80
Chloride Cl^-	$mmole_c$ L^{-1}	0.17	0.11	0.12	0.13
Sulphate SO_4^{2-}	$mmole_c$ L^{-1}	1.56	1.65	1.54	1.08

Table 2: Total number of irrigation, irrigation water applied, water use and ET_a of corn for the three irrigation levels.

Irrigation levels	No. of irrigation	WSIntial (mm)	WSLast (mm)	ΔS (mm)	Irrigation (mm)	Water use (mm)	Irrigation water saving (%)	ETa (mm)	ETa/ETm
I0	28	88	166	78	733	821	0	655	1
I1	28	88	126	38	588	676	19.8	550	0.84
I2	28	88	105	17	443	531	39.6	426	0.65

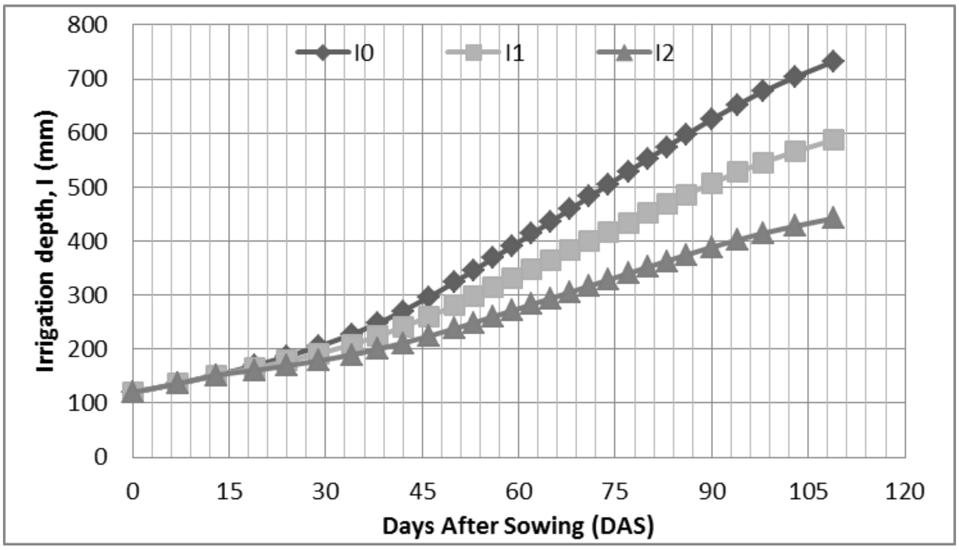


Fig.1: Cumulative depth of irrigation for different irrigation levels (I_0, I_1 and I_2).

When comparing ET_a and average ET_c for the first four periods (from 9-June to 30-September) it was noticed that ET_a and/or water equirements could be predicted from average ET_c (measured by *Blaney–Criddle* and *Hargreaves* equations), while for the last period (from 1 to 4- Otober) the prediction was inaccurate (Table 3). Average calculated crop coefficient (k_c) was 0.86 and 0.87 for 2007 and 1973-2006, respectively, indicating that they are about the same in value. Soil water stress coefficient (k_s= ET_a/ET_m) for I_0, I_1 and I_2 treatments were 1.00, 0.84 and 0.65, respectively.

The water analyses indicate the presence of three different directions: (1)Magnetic field did not exhibit any effect on some chemical omponents such as K^+, Na^+, CO_3^{2-}, NO_3^- as well as class and family of irrigation water. (2) Magnetic field has negative effect on Cl^-, RSC, SAR, adj.SAR, kinematic and dynamic viscosity. (3) Magnetic field has positive effect on EC, actual pH (pH_a), calculated pH (pH_c), total hardness (T.H.), saturation index (SI) , Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^{2-}, PO_4^{3-} and density of water (Table 4).

Average plant height decreased by 5.0 and 11.3% for I_1 and I_2, respectively, relative to I_0. Plant heights showed high significant ($p \leq 0.01$) increases averaging 5.6, 4.8 and 4.0% for B_1, B_2 and B_3, respectively, compared to B_0; while no significant differences ($p \leq 0.05$) were observed among B_1, B_2 and B_3. Maximum plant height level of 177.23 cm was observed for I_0B_1, whereas the minimum level of 147.89 cm was recorded for I_2B_0 (Table 5).

Average *TLN* decreased by 5.5 and 13.3% for I_1 and I_2, respectively, relative to I_0. Total leaf number showed significant ($p \leq 0.05$) increases averaging 4.2, 5.0 and 3.5% for B_1, B_2 and B_3, respectively, compared to B_0; while no significant differences ($p \leq 0.05$) were observed among B_1, B_2 and B_3. Maximum *TLN* level of 17.12 was observed for I_0B_2, whereas the minimum level of 14.12 was recorded for I_2B_0 (Table 5).

Average *LAI* decreased by 9.4 and 26.8% for I_1 and I_2, respectively, relative to I_0. Leaf area index showed significant ($p \leq 0.05$) increases averaging 9.1, 9.7 and 8.5% for B_1, B_2 and B_3, respectively, compared to B_0; while no significant differences ($p \leq 0.05$) were observed among B_1, B_2 and B_3. Maximum *LAI* level of 6.42 was observed for I_0B_2, whereas minimum level of 4.23 was recorded for I_2B_0 (Table 5).

Average stem radius decreased by 5.8 and 13.5% for I_1 and I_2, respectively, relative to I_0. Stem radius showed high significant ($p \leq 0.01$) increases averaging 6.9, 7.3 and 6.5% for B_1, B_2 and B_3, respectively, compared to B_0; while no significant differences ($p \leq 0.05$) were observed among B_1, B_2 and B_3. Maximum stem radius level of 1.778 cm was observed for I_0B_2, whereas minimum level of 1.428 cm was recorded for I_2B_0 (Table 5).

Average mass of dry roots decreased by 7.9 (not significant) and 25.3% for I1 and I2, respectively, relative to I0. Mass of dry roots showed high significant ($p \leqslant 0.05$) increases averaging 11.7, 11.5 and 10.4% for B1, B2 and B3, respectively, compared to B0; while no significant differences ($p \leqslant 0.05$) were observed among B1, B2 and B3. Maximum dry matter level of 3.560 Mg ha-1 was observed for I0B1, whereas minimum level of 2.324 Mg ha-1 was recorded for I2B0 (Table 5.(

Average grain yield decreased by 11.6 and 31.6% for I1 and I2, respectively, relative to I0. Grain yield showed high significant ($p \leqslant 0.01$) increases averaging 9.8, 12.1 and 10.5% for B1, B2 and B3, respectively, compared to B0; while no significant differences ($p \leqslant 0.05$) were observed among B1, B2 and B3. Maximum grain yield level of 8.03 Mg ha-1 was observed for I0B2, whereas minimum level of 4.81 Mg ha-1 was recorded for I2B0 (Table 5.(

Average aboveground dry matter decreased by 13.1 and 32.3% for I1 and I2, respectively, relative to I0. Aboveground dry matter showed high significant ($p \leqslant 0.01$) increases averaging 10.95, 12.90 and 10.90% for B1, B2 and B3, respectively, compared to B0; while no significant differences ($p \leqslant 0.05$) were observed among B1, B2 and B3. aximum total aboveground dry matter level of 23.19 Mg ha-1 was observed for I0B2, whereas minimum level of 13.73 Mg ha-1 was recorded for I2B0 .

Average mass of dry matter decreased by 13.9 and 32.3% for I1 and I2, respectively, relative to I0. Mass of dry matter showed high significant ($p \leqslant 0.01$) increases averaging 11.7, 13.4 and 11.3% for B1, B2 and B3, respectively, compared to B0; while no significant differences ($p \leqslant 0.05$) were observed among B1, B2 and B3. Maximum dry matter level of 15.16 Mg ha-1 was observed for I0B2 whereas minimum level of 8.92 Mg ha-1 was recorded for I2B0 .

Table 3: Reference evapotraspiration (ET_o) mm day $^{-1}$, calculated evapotranspitaion (ET_c) mm day $^{-1}$ and k_c for *Sulaimnyia* from 1973 to 2006 and 2007.

Periods	Days	k_c *	2007						1973-2006				
			Water balance equation	*Blaney–Criddle*		*Hargreaves*		average	*Blaney–Criddle*		*Hargreaves*		average
			ET_m **	ET_o	ET_c	ET_o	ET_c	ET_c	ET_o	ET_c	ET_o	ET_c	ET_c
9-30 Jun.	22	0.40	2.73	7.09	2.84	6.84	2.74	2.79	6.85	2.74	6.50	2.60	2.67
1-31 Jul.	31	0.76	5.12	7.42	5.64	6.72	5.11	5.37	7.44	5.65	6.90	5.24	5.45
1-31 Aug.	31	1.08	7.56	6.97	7.53	6.16	6.65	7.09	6.88	7.43	6.31	6.81	7.12
1-30 Sep.	30	0.81	5.90	6.03	4.88	5.26	4.26	4.57	5.85	4.74	5.03	4.07	4.41
1-4 Oct.	4	0.70	4.58	4.78	3.35	3.51	2.46	2.90	4.48	3.14	3.31	2.32	2.73

* Taken from *Irrigation and Drainage paper No. 56, FAO*, Rome, Italy (5).

** Values represent actual ET for I_0 treatment.

Table 4: Effects of magnetic treatments on chemical properties of water

Characteristics		Treatments			
		B0	B1	B2	B3
ECe ($dS\ m^{-1}$)at 25^oC		0.661	0.667	0.671	0.672
pHa		7.67	7.70	7.70	7.71
Total Hardness, T.H ($mg\ L^{-1}$)		319.5	325.0	327.5	329.0
Cations and Anions mmolec L^{-1}	Calcium Ca^{2+}	5.36	5.44	5.47	5.49
	Magnesium Mg^{2+}	1.03	1.06	1.08	1.09
	Potassium K^+	0.03	0.03	0.03	0.03
	Sodium Na^+	0.43	0.43	0.43	0.43
	Carbonate CO_3^{2-}	0.00	0.00	0.00	0.00
	Bicarbonate HCO_3^-	4.93	4.96	4.97	4.97
	Chloride Cl^-	1.07	1.03	0.98	0.92
	Sulphate SO_4^{2-}	0.54	0.65	0.73	0.82
	Nitrate NO_3^-	0.23	0.23	0.23	0.23
	Phosphorus PO_4^{3-}	0.084	0.091	0.096	0.098
SAR		0.2406	0.2385	0.2376	0.2371
pHc		7.1145	7.1175	7.1185	7.1185
RSC		-1.46	-1.54	-1.58	-1.61
adj.SAR		0.5498	0.5444	0.5421	0.5409
SI		0.5555	0.5825	0.5815	0.5915
Class [U.S Salinity Laboratory Staff (1954) SAR&EC]		C2-S1	C2-S1	C2-S1	C2-S1
Water family		Ca-HCO_3	Ca-HCO_3	Ca-HCO_3	Ca-HCO_3

Table 5: Some growth and yield parameters of corn as affected by irrigation levels and magnetic water treatments.

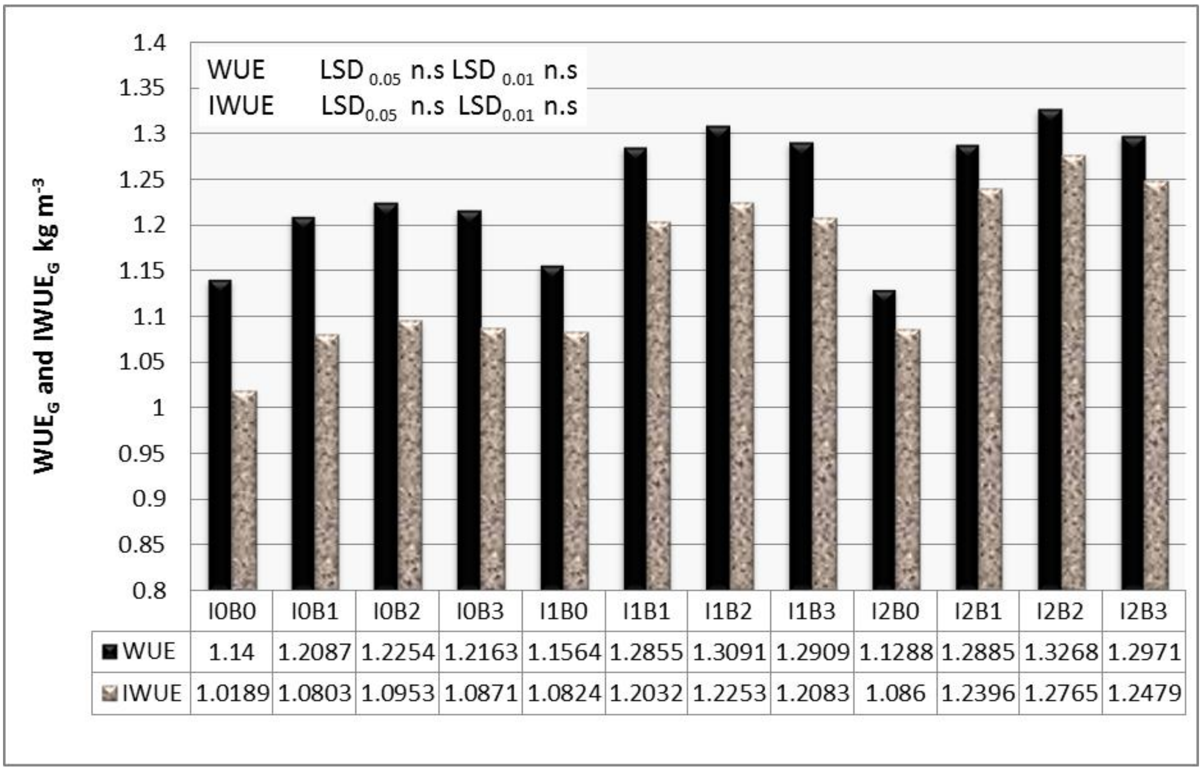
Treatments	Mean							
	Corn height (cm)	Total leaf number	Leaf area index	Stem radius (cm)	Root dry Mg ha^{-1}	Grain Yield Mg ha^{-1}	Shoot dry Mg ha^{-1}	Seed mass (g $1000seed^{-1}$)
B_0I_0	169.45	16.45	5.95	1.677	3.300	7.47	13.81	273.0
B_0I_1	160.31	15.40	5.32	1.569	2.954	6.37	11.50	244.6
B_0I_2	147.89	14.12	4.23	1.428	2.324	4.81	8.92	191.7
B_0	165.57	15.32	5.16	1.558	2.859	6.22	11.41	236.4
B_1I_0	177.23	17.00	6.38	1.777	3.560	7.92	14.99	287.5
B_1I_1	168.63	16.12	5.79	1.675	3.310	7.08	13.03	268.2
B_1I_2	158.34	14.78	4.73	1.543	2.710	5.49	10.18	214.4
B_1	166.86	15.97	5.63	1.665	3.194	6.83	12.74	256.7
B_2I_0	176.12	17.12	6.42	1.778	3.550	8.03	15.16	289.8
B_2I_1	167.41	16.23	5.83	1.683	3.307	7.21	13.25	271.1
B_2I_3	157.05	14.89	4.74	1.555	2.704	5.65	10.41	217.2
B_2	168.06	16.08	5.66	1.672	3.187	6.97	12.94	259.4
B_3I_0	174.89	16.89	6.35	1.772	3.530	7.97	14.95	285.4
B_3I_1	166.2	16.01	5.77	1.673	3.264	7.11	12.97	265.5
B_3I_2	155.62	14.67	4.68	1.534	2.674	5.53	10.13	212.5
B_3	159.22	15.86	5.60	1.659	3.156	6.87	12.69	254.5
I_0	174.42	16.87	6.27	1.751	3.485	7.85	14.73	283.9
I_1	165.64	15.94	5.68	1.650	3.209	6.94	12.69	262.3
I_2	154.72	14.62	4.59	1.515	2.603	5.73	9.91	209.0
$LSD_{0.05}$ for B	3.110	0.492	0.388	0.0450	0.170	0.290	0.272	17.3
$LSD_{0.05}$ for 1	0.386	0.769	0.535	0.0214	0.384	0.288	0.299	18.1
$LSD_{0.05}$ for B^*I	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s

05) were observed among B1, B2 and B3. Maximum total aboveground dry matter level of 23.19 Mg ha-1 was observed for I0B2, whereas minimum level of 13.73 Mg ha-1 was recorded for I2B0 .

Average 1000-grain mass decreased by 7.6 and 26.4% for I_1 and I_2, respectively, relative to I_0. Mass of 1000-Grain showed significant ($p \leq 0.05$) increases averaging 8.6, 9.7 and 7.6% for treatments B_1, B_2 and B_3, respectively, compared to B_0; while no significant differences ($p \leq 0.05$) were observed among B_1, B_2 and B_3. Maximum 1000-grain mass level of 289.8 gm was observed for I_0B_2, whereas minimum level of 191.7 gm was recorded for I_2B_0 (Table 5).

Values of WUE_G and $IWUE_G$ varied according to the irrigation treatments applied and they were as follows: 1.1976, 1.0704; 1.2605, 1.1798 and 1.2603, 1.2125 kg m^{-3} for I_0, I_1 and I_2, successively. Whereas WUE_G and $IWUE_G$ values were ranged from 1.1417-1.2871 and 1.0624-1.199 kg m^{-3}, respectively, as they were affected by magnetic water treatments. Values of WUE_G and $IWUE_G$ were the highest for I_2B_2 interaction, whereas the lowest values were noticed for I_2B_0 and I_0B_0, respectively (Fig. 2).

Fig.2: WUEG and IWUEG as affected by irrigation depth and magnetic water treatments



Values of WUE_{DM} and $IWUE_{DM}$ were the highest for I_2B_2 interaction, whereas the lowest values were noticed for I_1B_0 and I_0B_0, respectively (Fig. 3).

Values of WUE_{ADM} and $IWUE_{ADM}$ varied according to the irrigation treatments applied and they were as follows: 3.445, 3.080; 3.567, 3.338 and 3.588, 3.452 kg m^{-3} for I_0, I_1 and I_2, successively.

Values of WUE_{DM} and $IWUE_{DM}$ varied according to the irrigation treatments plied and they were as follows: 2.248, 2.009; 2.306, 2.159 and 2.328, 2.239 kg m^{-3} for I_0, I_1 and I_2, successively. Whereas WUE_{DM} and $IWUE_{DM}$ values were ranged from 2.098-2.389 and 1.952-2.225 kg m^{-3}, respectively, as they were affected by magnetic water treatments.

Values of WUE_{ADM} and $IWUE_{ADM}$ were the highest for I_2B_2 interaction, whereas the lowest values were noticed for I_2B_0 and I_0B_0, respectively (Fig. 4) Whereas WUE_{ADM} and $IWUE_{ADM}$ values were ranged from 3.239-3.676 and 3.015-3.424 kg m^{-3}, respectively, as they were affected by magnetic water treatments.

Fig. 3: WUEDM and IWUEDM as affected by irrigation depth and magnetic water treatments

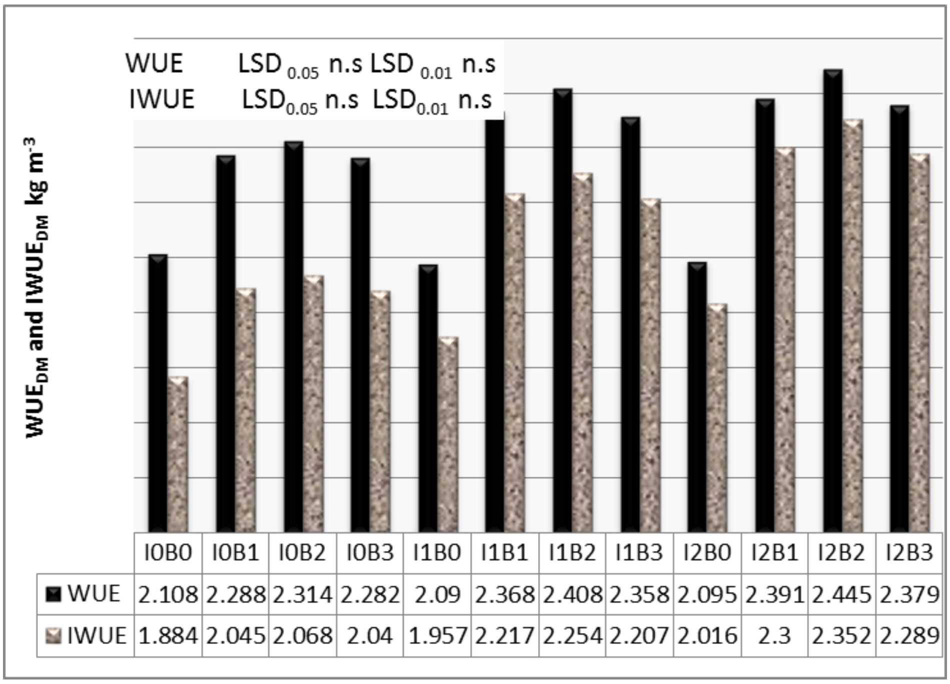
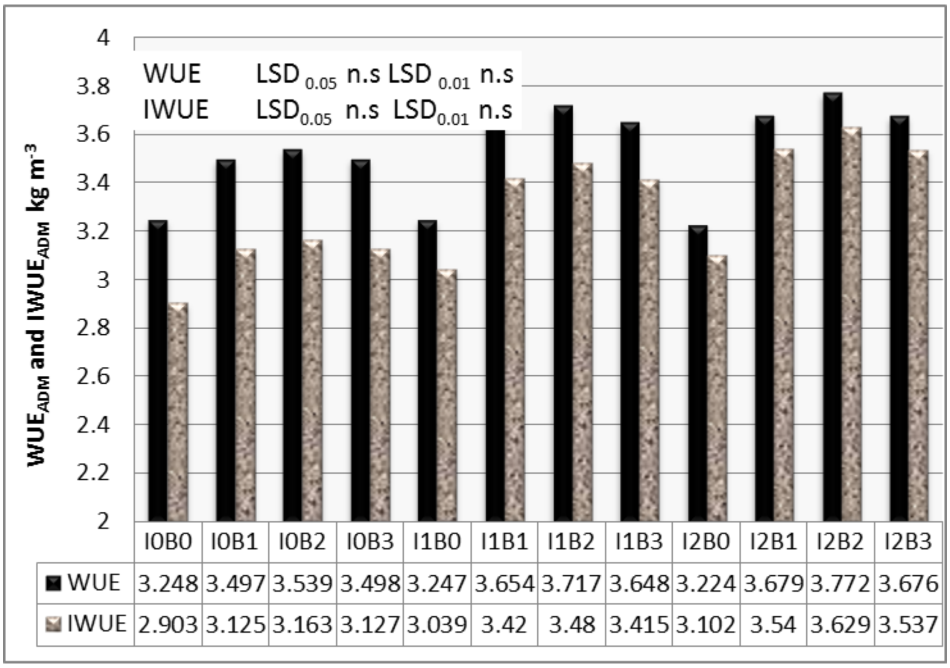


Fig. 4: WUEADM and IWUEADM as affected by irrigation depth and magnetic water treatments



In all treatments grain yield tended to increase with increasing ET_a up to the point where ET_a became ET_m ($ET_a = ET_m$ with no water stress). Different yield versus ET_a/ET_m functions were plotted for each magnetic water treatments, with a steeper slope observed for B_0 compared with the others (Fig. 5). Table (6) shows the percentages of yield increase as a resut of magnetic water treatments. Average values of k_y were 0.909, 1.018; 0.662, 0.877; 0.634, 0.845 and 0.670, 0.876 for I_1 and I_2 in combination with I_0 under B_0, B_1, B_2 and B_3 treatments. The k_y values to water deficit for the entire growing season were 1.11, 1.06, 1.02 and 1.05 in B_0, B_1, B_2 and B_3, respectively (Table 7).

Fig. 5: Response of grain yield to different ETa/ETm and magnetic flux density.

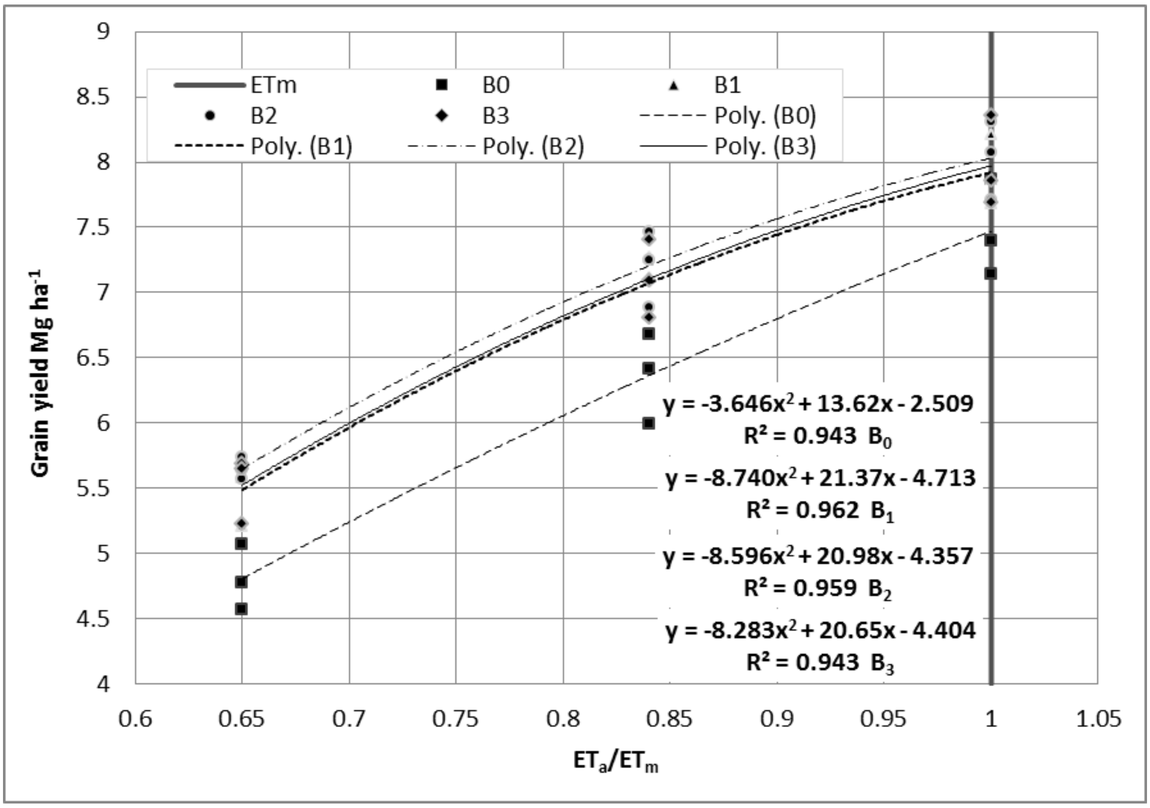


Table 6:The percentage of yield increase at different ranges of ETa/ETm ratio for different magnetic treatments.

Magnetic water treatments	ETa/ETm		
	0.65 to 0.84	0.84 to 1.00	0.65 to 1.00
B0	24.5	14.7	35.6
B1	22.5	10.6	30.7
B2	21.6	10.2	29.6
B3	22.2	10.8	30.6

Table 7:Crop response factor at different levels of irrigation and magnetic water treatments

Magnetic water treatments	Average ky	
	I0-I1	I0-I2
B0	0.909	1.018
B1	0.662	0.877
B2	0.634	0.845
B3	0.670	0.876

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The crop water response factor k_y was otained as the slope of ploting ($1\text{-}Y_a/Y_m$) versus ($1\text{-}Et_a/ET_m$) of Equation (5). This was done for all megnetic treatments and the results are shown on Figures (6), (7), (8), and (9).

.Fig. 6: Yield reduction vs. evapotranspiration deficit for B0 treatment

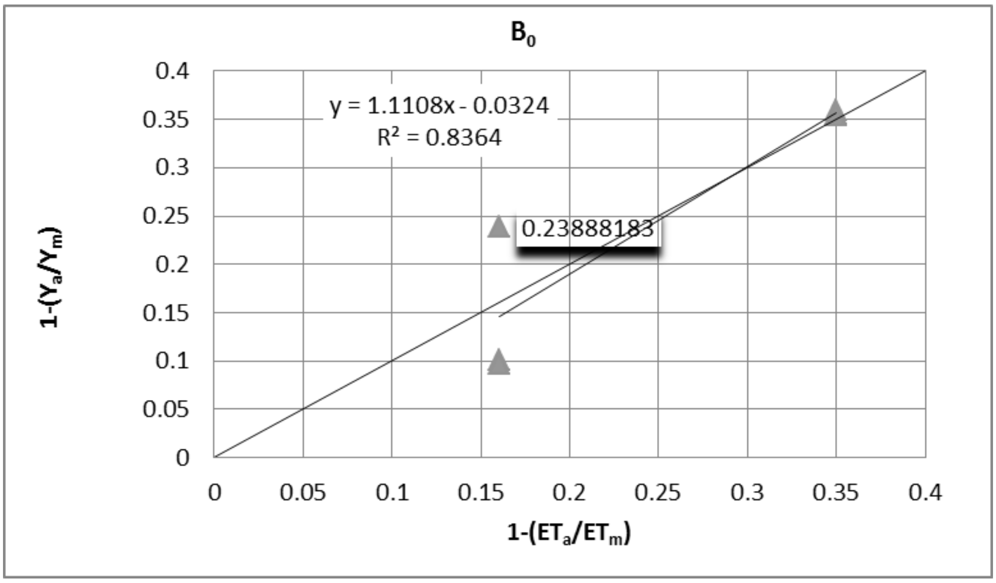


Fig. 7: Yield reduction vs. evapotranspiration deficit for B1 treatment.

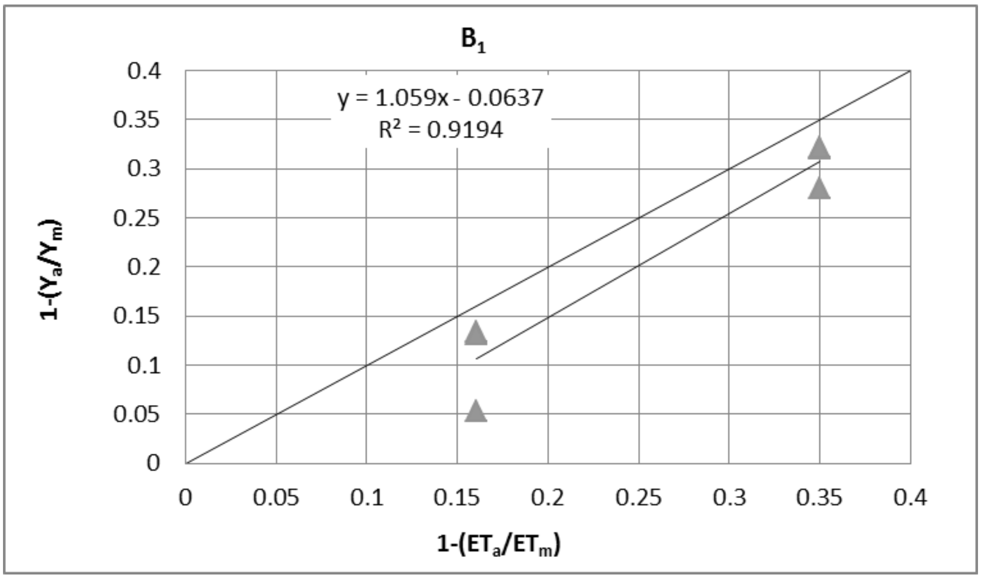


Fig. 8: Yield reduction vs. evapotranspiration deficit for B2 treatment.

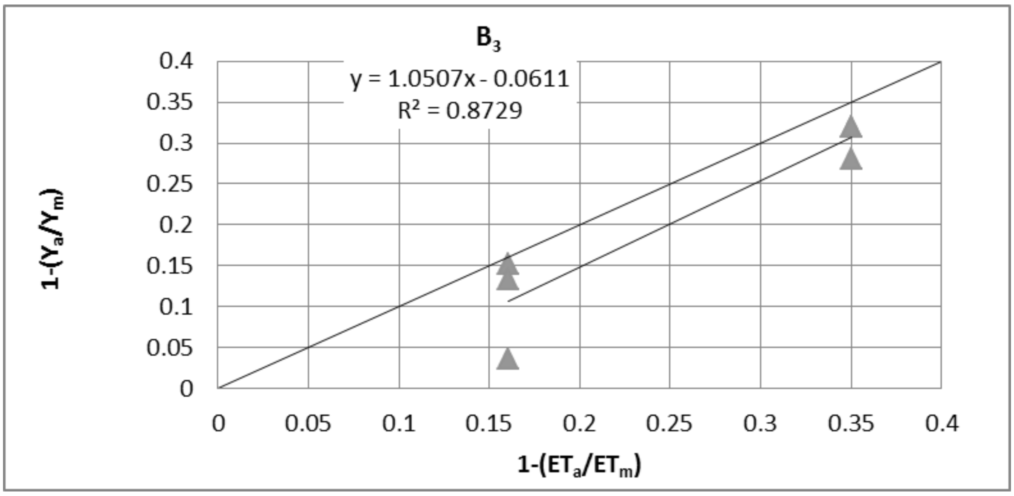
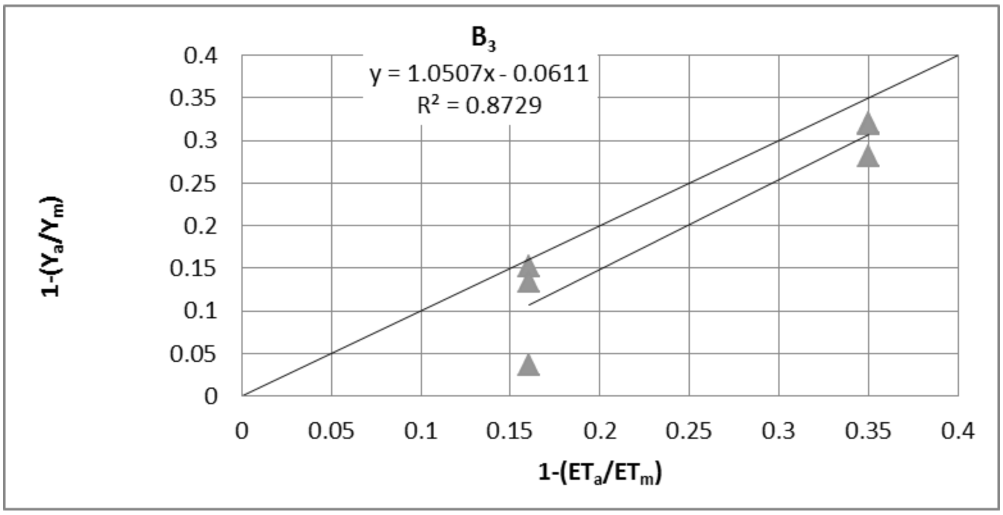


Fig. 9: Yield reduction vs. evapotranspiration deficit for B3 treatment.



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