YIELD PRODUCTION AND WATER USE EFFICIENCY UNDER CONVENTIONAL AND ALTERNATE FURROW FERTIGATIONS

RENDEMENT ET UTILISATION EFFICIENTE DE L'EAU DANS LES FERTIGATIONS PAR SILLONS CLASSIQUES ET ALTERNÉS

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ABSTRACT

Increasing water productivity in agricultural lands is a challenge to mitigate the water crisis in arid and semi-arid regions like Iran. Alternate furrow irrigation, as deficit irrigation, could be applied in agricultural fields for saving more water. Also surface fertigation could reduce fertilizer losses and improve distribution uniformity of the fertilizer. The goal of this paper was to apply surface fertigation in alternate furrow irrigation and compare it with conventional furrow irrigation in terms of yield production and water use efficiency (WUE). Field experiment was done for one growing season of the maize for three different furrow irrigations: variable alternate furrow irrigation (AFI), fixed alternate furrow irrigation (FFI) and conventional furrow irrigation (CFI), in the research farm of University of Tehran, Karaj, Iran. Total applied irrigation volume and the biomass and dry matters in the beginning, middle and end parts of the experimental field were measured for all irrigation treatments. The highest biomass and dry matters were obtained in CFI (55.0 and 20.2 ton ha^{-1}, respectively). Whereas FFI had the lowest values for the biomass and dry matters (27.3 and 8.3 ton ha^{-1}, respectively). WUE value was 2.82 kg m^{-3} for AFI, 1.31 kg m^{-3} for FFI and 1.61 kg m^{-3} for CFI, respectively. AFI not only decreased water and fertilizer consumptions but also significantly increased water use efficiency. In fact alternative drying of the root zone could improve the distribution of the roots on both sides of the ridge to uptake more water and fertilizer.

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Key words: *Alternate furrow, surface fertigation, water use efficiency, University of Tehran.*

RESUME ET CONCLUSIONS

L'augmentation de la productivité de l'eau est cruciale dans les régions arides et semi-arides. Le développement de nouvelles méthodes pour réduire les pertes d'eau du secteur agricole peut atténuer la pénurie d'eau. Le système d'irrigation par sillons alternés peut être utilisé dans les champs en tant qu'un moyen d'irrigation déficitaire pour la conservation de l'eau. La fertigation de surface peut réduire les pertes d'engrais et améliorer l'uniformité de distribution d'engrais. Le rapport vise à metre en place la fertigation de surface dans le système d'irrigation par sillons alternés et ensuite compare les données obtenues avec celles du système classique d'irrigation par sillons en ce qui concerne le rendement et l'utilisation efficiente de l'eau (WUE). L'expérimentation fut menée dans la ferme de recherche de l'Université de Téhéran, Karaj (Iran) lors d'une saison de croissance du maïs utilisant trois différents types d'irrigation par sillons: irrigation par sillon alterné variable (AFI), irrigation par sillon alterné fixe (FFI) et irrigation par sillon classique (FCI). Le volume total d'irrigation appliqué, de la biomasse et des matières sèches au début, au milieu et en fin d'expérimentation ont été mesurés pour tous les traitements d'irrigation. La plus forte biomasse et les matières sèches ont été obtenus dans FCI (55,0 et 20,2 t/ha-1 respectivement). Tandis que FFI a obtenu les plus faibles valeurs de la biomasse et des matières sèches (27,3 et 8,3 t/ha-1 respectivement). La Valeur de WUE était de 2,82 kg/m-3 pour AFI, 1,31 kg/m-3 pour FFI et 1,61 kg/m-3 pour FCI respectivement. Le système AFI a non seulement diminué la consommation d'eau et d'engrais, mais a aussi augmenté l'efficience d'utilisation de l'eau. En fait, le séchage de la zone de racine pourrait améliorer la répartition des racines sur les deux côtés de la crête à l'absorption d'eau et d'engrais.

Mots clés : *Sillons alternés, fertigation de surface, efficience en utilisation de l'eau, Université de Téhéran.*

1. INTRODUCTION

Increasing water productivity is crucial in arid and semi-arid regions. Development of new methods for reducing water loss in agriculture sector can mitigate the water shortage. Deficit irrigation including alternate furrow irrigation could be applied in agricultural land with limited available irrigation water. Surface fertigation has many advantages such as; low labor cost, high uniformity and low nutrients losses (Perea et al., 2010). The pollution of water resources can be reduced using good design and management of the fertigation in furrow irrigation.

Kang et al. (2000) evaluated the alternate furrow irrigation (AFI), fixed furrow irrigation (FFI) and conventional furrow irrigation (CFI) with different irrigation amounts for maize production. They reported that yield reduction in AFI was not significant unlike FFI. Mohajer Milani et al. (2004) investigated application of the saline water in furrow irrigation systems for cotton and maize productions. Water productivity in the alternate furrow irrigation was greater than that in conventional furrow irrigation. Horst et al. (2007) applied surge flow to alternate furrows in cotton fields. The performance of alternate furrow irrigation considerably increased and provided the highest water productivity (0.61 kg m^{-3}) and irrigation application efficiency

(85 %) as compared to the conventional furrow irrigation. Alternate furrow irrigation also increased water use efficiency in wheat-cotton rotation in Punjab, India (Thind et al., 2010). Moreover, application of the alternate furrow irrigation increased water productivity rather than conventional furrow irrigation in sugarcane fields in southern part of Iran (Sheyni Dashtgol et al., 2009). Slatni et al. (2011) conducted field experiment to evaluate three irrigation systems including AFI, FFI and CFI for a potato crop. Application and irrigation efficiency were the highest in FFI and lowest in CFI. Water productivity was reported to be 8.0, 8.7 and 5.9 kg m^{-3} for the AFI, FFI and CFI treatments, respectively.

Some researchers reported that more fertilizer is retained in the soil and become available for plants because of lower nitrate leaching (Mitchell et al. 1994; Benjamin et al. 1998; Skinner et al. 1999). Since, fertigation has numerous advantages and agricultural water resources are limited in arid and semi-arid regions, application of both alternate furrow irrigation and fertigation could be necessary in such regions such as in Iran. The objective of the study reported in this paper was to investigate the performance of two alternate furrow irrigations (AFI and FFI) under fertigation and compare it with the conventional furrow irrigation for maize production in a semi-Mediterranean area.

2. MATERIALS AND METHODS

Field experiment was conducted in the experimental station of the College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran. This zone has a semi-Mediterranean climate with an average annual rainfall of 265mm and an average annual temperature of 16 ºC. Physical and chemical soil properties of the experimental field are given in Table 1. Soil texture of the experimental filed was loam with an underlying well-drained medium of gravel at 0.6 m depth. Maize (*single cross 704*) was cultivated for one growing season (June 10 to September 15, 2010). Of the required fertilizer, 10% (200 kg N ha^{-1}) was applied on the day before sowing (by fertilization practice) and three equivalent parts (each 30%) for the growth stages of vegetative (seven leaves in July 7), flowering (August 9) and grain filling (August 30) using fertigation practice. Evapotranspiration values were estimated by CROPWAT during the growing season. Three furrow irrigation methods; conventional, alternate, and fixed furrow irrigations were applied. AFI means that one of the two adjacent furrows was alternately irrigated during consecutive watering. FFI means that irrigation was fixed to one of the two adjacent furrows. CFI means that every furrow was irrigated during each watering. Fourteen furrows were established (6, 5, and 3 furrows for AFI, FFI, and CFI, respectively) with a spacing of 0.75m, a slope of 0.0093 and a length of 86m. All treatments were irrigated 14 times during the growing season at 7-day intervals. Water and fertilizer (ammonium nitrate) amounts were equivalent for all irrigated furrows in three irrigation methods. Irrigation and fertilizer solution injection systems are shown in Figure 1 for FFI. Inflow rates were measured by WSC flumes installed at the inlet and outlet of the experimental furrows. Table 2 shows the summary data of the three fertigations included discharge, cutoff time, start time of injection, injection duration, injection rate and nitrate concentrations in the fertilizer tank and irrigation water. Yield production at the beginning, middle, and end of the experimental field were measured for all irrigation. Water use efficiency (WUE) was calculated based on the total volume of irrigation water and maize yield. WUE is the ratio of the dry matter mass (kg) to total applied irrigation volume (m^3).

Table 1. Physical and chemical soil properties of the experimental field (Physiques et chimiques des propriétés du sol du champ experimental)

Depth (cm)	texture	Bulk density (g/cm^3)	FC (-)	PWP (-)	Organic matter (%)	pH	EC_e (dS/m)
0-20	Clay loam	1.506	0.181	0.084	1.83	7.63	2.76
20-40	Loam	1.483	0.177	0.081	1.18	7.71	2.02
40-60	Sandy loam	1.489	0.150	0.066	0.68	7.71	1.98

Table 2. Data summary of fertigations (Sommaire des données de fertigations)

Fertigation	Discharge (lit/s)	Cutoff time (min)	Start time of injection (min)	Injection duration (min)	Injection rate (lit/hr)
First	0.262	240	after advance time	150	4.28
Second	0.388	360	0	180	3.57
Third	0.321	300	270	30	21.4

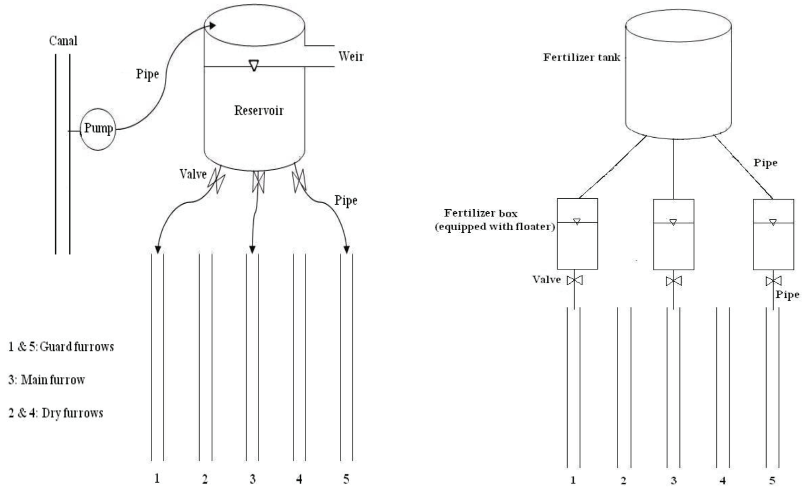

Fig. 1. Schematic of water distribution and fertilizer solution injection systems for FFI (Schéma de distribution d'eau et d'engrais solution systèmes d'injection pour FFI)

3. RESULTS AND DISCUSSION

Total yield (dry or biomass matter) was calculated by averaging three samples in the beginning, middle and end of the experimental field. The biomass and dry matters, total irrigation volume and water use efficiency (WUE) are given in Table 3. The data were analyzed using completely randomize design, Duncan's test (1% level) and factorial experiment (by SPSS program) to explain the significant difference among all the irrigation treatments in terms of biomass and dry matters.

With increasing distance from the upstream end of the field, the yield (biomass and dry matters) decreased for all the irrigation treatments (Figures 2&3). The yield in the beginning part of the experimental field was more than that in the middle and end parts because of more water and fertilizer infiltration in the beginning part. Both the biomass and dry matters of the beginning part had a significant difference with other parts whereas there was no significant difference between the middle and end parts.

The yield was nearly the same in both CFI and AFI treatments (especially the dry matter), although total applied irrigation volume was almost double in CFI related to AFI method. Then there was no significant difference between CFI and AFI in terms of the biomass and dry matters. While the yield decreased significantly in FFI compared to AFI. In fact, AFI had smaller yield reduction relative to FFI. The highest biomass and dry matters were obtained in CFI (55.0 and 20.2 ton ha^{-1}, respectively), but AFI had the highest WUE (2.82 kg m^{-3}). The WUE values for CFI and FFI were 1.61 and 1.31 kg m^{-3}, respectively. FFI not only decreased the biomass and dry matters (27.3 and 8.3 ton ha^{-1}, respectively) but also had the lowest WUE relative to two other irrigation treatments.

The reason of having more WUE and lower reduction in the yield for AFI could be related to better distribution of the roots in both sides of the ridge. It could increase water and fertilizer uptakes by plants. The results showed that alternative drying of the root zone had better performance than the fixed drying of the root zone. This probably caused further adaptation of the roots to uptake more water and fertilizer. Mohajer Milani et al. (2004) showed that AFI increased WUE for maize (1.37 kg m^{-3}) relative to CFI. The study of Kang et al. (2000) also indicated that AFI had better performance for increasing WUE (2.76-5.75 kg m^{-3}) relative to FFI and CFI in maize field in an arid area. Whereas Sepaskhah and Parand (2006) stated that alternate furrow irrigation resulted in significant reduction in maize grain yield.

Table 3. Biomass and dry matters and WUE values for all irrigation treatments (La biomasse et sec questions et VUE valeurs pour toutes l'irrigation traitements)

Irrigation	Field location	Biomass (t ha^{-1})	Dry matter (t ha^{-1})	Irrigation volume (m^3)	WUE (kg m^{-3})
CFI	beginning	69.0	25.0		
	middle	50.0	18.4		
	end	46.0	17.3		
	average	55.0 ^{a}	20.2 ^{a}	12535.3	1.614
FFI	beginning	37.0	11.1		
	middle	28.0	8.3		
	end	17.0	5.6		
	average	27.3 ^{b}	8.3 ^{b}	6359.4	1.310
AFI	beginning	65.0	24.8		
	middle	43.0	18.8		
	end	41.0	14.0		
	average	49.7 ^{a}	19.2 ^{a}	6801.8	2.823

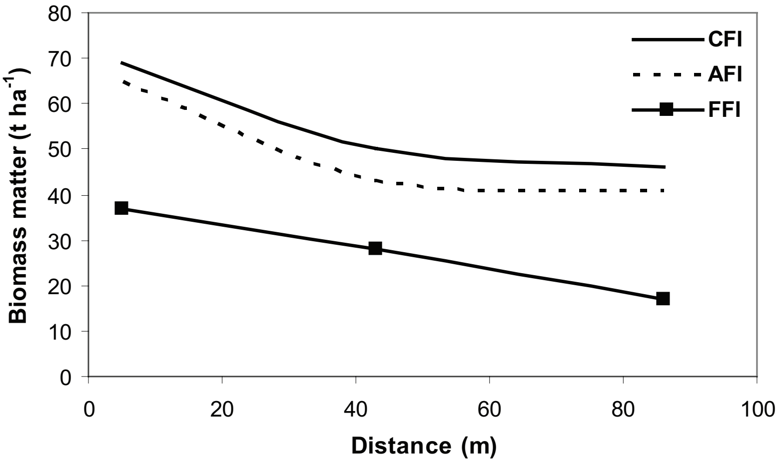

Fig. 2. Biomass along the furrow for all irrigation treatments (Biomasse question ainsi le sillon pour tous les traitements irrigation)

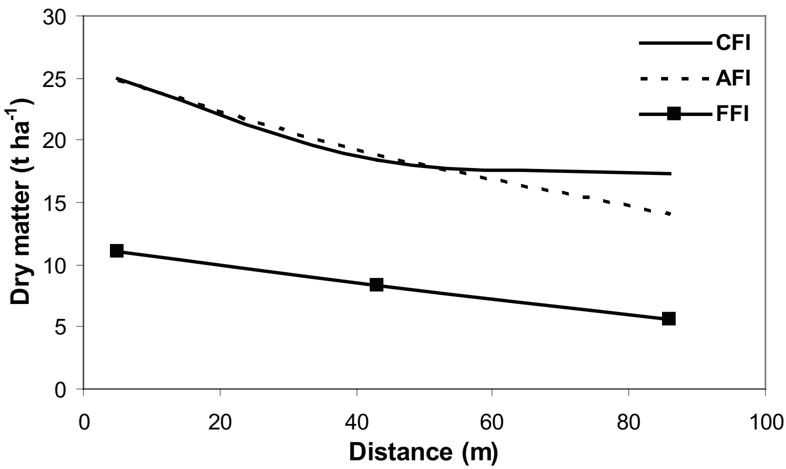

Fig. 3. Dry matter along the furrow for all irrigation treatments (Matière sèche ainsi le sillon pour tous les traitements irrigation)

4. CONCLUSIONS

In this study, the field experiment under three fertigations was carried out to compare three furrow irrigation methods (AFI, FFI and CFI) in terms of the yield production (biomass and dry matters) and water use efficiency (WUE). Although CFI had the highest value of the biomass and dry matters, AFI significantly increased WUE (2.82 kg m^{-3}). It meant that AFI had small reduction in the yield. While FFI had the lowest values of the biomass and dry matters and WUE. There was significant difference between the yield values in the beginning part and the middle and end parts of the experimental field.

AFI caused water saving up to 50 percents. By application of alternate furrow irrigation, the cultivated area could be increased especially in regions having uncultivated lands. The alternate furrow irrigation could decrease water losses such as deep percolation and runoff in the fields and increased irrigation efficiency and water use efficiency. Additionally, it could reduce the fertilizer consumption to 50 percents as well. If the alternate furrow fertigation is designed and managed well, it can improve water and fertilizer uniformities and application efficiencies. It has a potential to decrease the environmental hazards of the agriculture activities on groundwater and surface water bodies. As an overall conclusion, the alternate furrow fertigation can be suitable for areas with limited water resources regarding its advantages and possibilities.

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