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Interactions of irrigation, weed and nitrogen on corn yield, nitrogen use efficiency and nitrate leaching

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ABSTRACT

The effects of water, N and weed interactions on crop performance have not been adequately addressed. The main objectives of this study, which was conducted in a semi-arid region of Iran during the 2010 and 2011 growing seasons, were to determine the effects of interactions among irrigation regimes (I), weed competition (W) and N rates on corn yield, dry matter and grain N concentration, N use efficiency and nitrate leaching in a sandy soil. The experiment was carried out using a randomized complete block design with a split factorial arrangement of treatments in four replications. The main plots were subjected to the following irrigation treatments: Low frequency irrigation (I_1) and high frequency irrigation (I_2). The subplots consisted of a factorial combination of four N levels (0, 150, 300 and 450 kg N ha^{1}) and two levels of redroot pigweed interference with corn (weed free, W_0; and weedy, W_1). When averaged over both years, the results showed that the enhancement of applied N (0–450 kg N ha^{-1}) increased corn grain yield by 63% with high frequency irrigation and by 25% with low frequency irrigation. Moreover, the results showed that the enhancement of applied N from 0 to 450 kg N ha^{-1} resulted in a ten- and six-fold increase in nitrate leaching loss (NLL) with the high and low frequency irrigation regimes, respectively. In both the weedy and weed free treatments, the NLL increased, but the NLL intensity decreased in response to the enhancement of applied N in the presence of weeds. The mean comparisons of N use efficiency showed that in the N_{150} treatment, each kilogram of applied N led to the production of 19 and 14 kg grain ha^{-1} with high and low frequency irrigation, respectively. In contrast, in the N_{450} treatment, each kilogram of applied N resulted in the production of 8 and 5 kg grain ha^{-1} in the high and low frequency irrigation regimes, respectively. Finally, results showed that it is necessary to achieve equilibrium between applied water and N, especially in sandy soils, which will lead to a reduction in the indiscriminate application of nitrogen fertilizer that does not effectively increase the corn yield whereas it severely increases nitrate leaching loss.

1. Introduction

In most agricultural areas of the world, the corn (*Zea mays* L.) yield potential is commonly controlled and limited by water deficit stress, limited N availability and weed interference. The interaction of water, N and weed is complex and is further complicated by soil and climatic variability (Ruf, 2007). Furthermore, the effects of interactions of water, N and weed have not been adequately addressed. Recently there has been interest in reducing and optimizing irrigation application due to water scarcity in agricultural lands. Soil water status is important in maintaining maximum corn yields, and maintaining optimal soil water is facilitated by high irrigation application in areas of light-textured soil (Derby et al., 2005).

Following the importance of water, N has a significant role in realizing the maximum potential of the crop. Nitrogen is the most important nutrient for crop yield and sustainability of the environment (Li et al., 2007). For this reason, the efficient use of N fertilizers in crop production is of major importance (Rathke et al., 2006). Lopez-Bellido et al. (2005) suggested that maximizing N efficiency is an increasingly important objective in most crop management systems. In most situations, however, the efficiency of N fertilizer is fairly low ranging from 30% to 50% of the applied fertilizer, and 20% to 70% is lost from soil-crop systems (Dawson et al., 2008). Low N efficiency is not entirely free from risk. In some soils, especially light-textured ones, intensive use of N fertilizer may lead to nitrate leaching. Because N is a mobile nutrient in soil and when it is

Abbreviations: NUE, N use efficiency; DMNC, dry matter N concentration; GNC, grain N concentration; NLL, nitrate leaching loss.

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Table 1
Meteorological, water balance and irrigation efficiency data.

	[a]AV (°C)	P (mm)	RE (mm day^{-1})	AC K_C	AW K_C	K_S	ΔSW L (mm month^{-1})	ΔSW H (mm month^{-1})	L Ir (mm)	DPL (mm)	H Ir (mm)	DPH (mm)
2010												
June	28	1.2	10.20	0.30	0.15	0.30	73 (70)[b]	153 (122)[b]	135	35 (25)[b]	289	45 (30)[b]
July	32	0	10.62	0.45	0.20	0.40	113 (96)	102 (56)	213	43 (34)	307	62 (44)
August	30	0.5	8.45	0.55	0.25	0.45	32 (13)	84 (39)	116	21 (12)	268	45 (26)
September	29	1.2	7.81	0.30	0.20	0.40	47 (44)	49 (31)	81	16 (7)	120	25 (12)
Total		2.9							545	115 (78)	984	177 (112)
2011												
June	25	2.3	9.76	0.30	0.15	0.25	70 (67)	116 (86)	126	36 (28)	249	47 (33)
July	30	2.1	9.54	0.45	0.20	0.35	140 (128)	118 (64)	209	26 (13)	299	54 (37)
August	27	0.5	7.13	0.60	0.3	0.45	42 (27)	68 (18)	125	25 (11)	236	40 (26)
September	24	7.8	6.31	0.35	0.2	0.35	41 (40)	28 (11)	62	13 (6)	83	19 (11)
TOTAL		12.7							522	100 (58)	867	160 (107)

Long term (30 years)			CEL in 2010 (mm month^{-1})	CEH in 2010 (mm month^{-1})	CEL in 2011 (mm month^{-1})	CEH in 2011 (mm month^{-1})	[c]Irrigation water productivity (kg mm^{-1})	2010	2011
June	25	4.1	28 (41)[b]	92 (138)[b]	22 (33)[b]	88 (132)[b]	Low frequency irrigation	3.7	3.8
July	30	0.5	57 (83)	143 (207)	45 (70)	129 (200)	High frequency irrigation.	2.9	3.4
August	28	0	63 (91)	139 (203)	58 (87)	128 (193)			
September	22	11.2	19 (31)	47 (78)	15 (24)	44 (69)			
Total		15.8	166 (247)	421 (626)	140 (214)	389 (594)			

[a] AV: average temperature; P: precipitation; RE: reference evapotranspiration; AC K_C: average corn K_C; AW K_C: average weed K_C; and K_S: correction coefficient (with no dimension) for calculating ET_C under water deficiency conditions. ΔSW L: monthly change in soil water content (mm) at the depth of root development in low frequency irrigation (measured by TDR). ΔSW H: monthly change in soil water content (mm) at the depth of root development in high frequency irrigation (measured by TDR). L Ir: irrigation amounts in low frequency irrigation; H Ir: irrigation amounts in high frequency irrigation; DPL: deep percolation in low frequency irrigation; DPH: deep percolation in high frequency irrigation; CEL: crop evapotranspiration in low frequency irrigation; and CEH: crop evapotranspiration in high frequency irrigation.

[b] Data in parenthesis are related to weedy plots.

[c] Irrigation water productivity was calculated as grain yield (kg ha^{-1}) divided by total seasonal applied irrigation water (mm). Growing period of plants in September was 20 days.

combined with water during over-application (which often occurs, especially in sandy soils), elevated levels of N in ground and surface water occur. Several studies have investigated the effect of water and N rate interactions on corn yield and nitrate leaching in corn farms (Sexton et al., 1996; Al-Kaisi and Yin, 2003; Jaynes and Colvin, 2006; Di Paolo and Rinaldi, 2008). In general, an increase in soil water enhances corn yield response to N fertilization (Di Paolo and Rinaldi, 2008). Evaluating the response of corn to the combination of irrigation and N may help to identify an appropriate application of water and N to maximize profit and reduce groundwater pollution.

Whenever a crop emerges, weeds also appear. Weeds compete with crops for water, light and nutrients, and uncontrolled weeds can stunt crop growth (Zoschke and Quadranti, 2002). In addition to water and N, weed competition is a major constraint to corn production. Weeds can reduce the corn grain yield by 35–70% when not controlled (Mohammadi, 2007). The outcome of competition will depend on the crop and weed species as well as their density and level of fertility. Among the most important weed species in terms of growth in corn fields, one of the most aggressive species is redroot pigweed (*Amaranthus retroflexus* L.). Redroot pigweed is a small-seeded, broadleaf weed distributed throughout Iran and other areas of the world. When redroot pigweed emerges with corn, grain yields are reduced by as much as 34% (Knezevic et al., 1994).

The management of water availability and N fertilization should be tailored to optimize N efficiency, decrease N leaching and reduce weed interference. Zoschke and Quadranti (2002) reported that the interaction of irrigation regimes and N fertilization on weed interference with crops is not fully understood. Some evidence indicates that high soil fertility levels stimulate crop growth relative to weed growth (Tollenaar et al., 1994; Abouziena et al., 2007) whereas other studies suggest that high nutrient levels favor weed growth and increase crop yield loss (Berger et al., 2007; Burgos et al., 2006). According to our literature review, there is no comprehensive information on the effect of water, N and weed interference as well as their interactions on corn yield, N efficiency index and N leaching in sandy soils. Therefore, because these crucial traits have never been measured in common experiments, especially in sandy soils, the objective of this study was to evaluate the impact of irrigation regimes, N fertilization rates and redroot pigweed interference as well as their interactions on corn yield, corn N concentration, N efficiency index and N leaching.

2. Materials and methods

2.1. Experiment location and general methodology

The experiment was conducted on a sandy loam soil during the 2010 and 2011 growing seasons at the research farm of Tarbiat Modares University, Tehran, Iran (35°41′ N, 51°19′ E and 1215 masl). The region is characterized as semi-arid, with mean annual precipitation of 298 mm, which mostly falls during the autumn and winter months. Daily meteorological data of precipitation and air temperature (Table 1) were obtained from the nearest weather station (500 m from the experimental site). Before planting, 30 soil samples were taken at depths of 0–30 and 30–60 cm, composite samples were collected, air-dried, crushed, and tested for physical and chemical properties (Table 2).

2.2. Land preparation and introduction of treatments

Corn was planted in different sections of the field each year following canola (*Brassica napus* L.) in 2010 and wheat (*Triticum aestivum* L.) in 2011. The field was prepared by shallow plowing followed by disking in late May. Each experimental unit was 8 m long and consisted of 7 rows spaced 0.75 m apart. There were