Effect of water stress and nitrogen application on grain yield of wheat

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Abstract

Crop production in arid and semi- arid regions is restricted by soil deficiencies in moisture and plant nutrients(especially nitrogen). Consequently adequate levels of irrigation and nitrogen (N) are needed to secure high yields (E lsiddig 1998). The high cost of fertilizer nitrogen raises the question about the feasibility of applying N fertilizer under limited soil moisture condition. For that field experiments were conducted at the Gezira Research Station Farm, for two seasons to evaluate the combined effects of water stress and nitrogen (N) on the productivity of two wheat cultivars as well as nitrogen use efficiency (NUE). As expected the results indicated that, under normal irrigation grain yield of both cultivars increased with increasing levels of N. However, under limited soil moisture conditions, water stress is a more yield limiting factor than N fertilization for wheat production under hot dry environments. It is recommended to use only 43 kg N ha^{-1} in areas of known irrigation problems. Nitrogen use efficiency was found to decrease with increasing N level and under water stress it was reduced to half its values under normal irrigation. Both N application and frequent watering increased total N-uptake and grain yield of wheat (*Triticum aestivum* L.) grown under water and nitrogen stresses in hot dry environments.

Introduction

Crop production in arid and semi-arid regions is restricted by soil deficiencies in moisture and plant nutrients (especially nitrogen). Consequently adequate levels of irrigation and nitrogen (N) fertilizer are needed (Elsiddig 1998). Addition of N fertilizer to wheat is required to ensure that N is available throughout the growing season due to its important role in promoting both vegetative and reproductive growth. High yielding wheat varieties need large and regular supply of N to develop high photosynthetic capacity and maintain the proper nitrogen concentration in the leaves so that CO_2 assimilation is not affected when large rates are required for ear growth and grain-filling period (Lawlor, 1995).

The importance of N fertilization in increasing wheat production has been well documented, but still it is difficult to determine the quantities to apply under water stress condition. This is due partly to lack of information on N-uptake and N-distribution among plant parts under these conditions.

Wheat in Sudan is grown entirely under irrigation during the short dry and comparatively cool winter season that extends from November to March. High temperatures prevail during the beginning and the end of the cropping cycle. Irrigation water and nitrogen fertilizers are the most crucial components of the production package (soils of wheat growing areas are inherently deficient in N). As wheat is an irrigated crop, its production is frequently exposed to water deficits at any stage of the crop development. The high cost of fertilizer nitrogen raises the question about the feasibility of applying N fertilizer under limited soil moisture conditions.

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This study was intended to investigate the combined effects of water stress and nitrogen on wheat growth and productivity and thus determine nitrogen requirement under hot dry environment

Materials and methods

The experiments were conducted at the Gezira Research Farm, Wad Medani, Sudan (latitude 14º24'N, longitude 33º31'E, altitude 981 m) during 1997-98 and 1998-99 cropping seasons. The soils of the experimental site are heavy craking Vertisols classified as fine Smectitic isohyperthermic Chromic Haplusterts, Remeitab soil series (non-sodic phase). Soil characterization is shown in Table 1.

The experiments were laid out in a split-split plot design with three replications. Irrigation regimes, normal and stress (depending on soil moisture depletion, normal is 50 % soil moisture depletion while stress is 75 %) occupied the main plots, while varieties (Condor and Elneilain) were assigned to the sub-plots and N-levels (0, 22, 43, 65, 86, 108 and 129 kg N ha^{-1}) were allocated to the sub-subplots. Each subplot consisted of 10 or 15 rows 5 m long with 0.2 m inter row spacing for the first and second season, respectively. Planting dates were on 25 Nov 1997 and 17 Nov 1998 at a seed rate of 120 kg ha^{-1}. Planting was done manually by hand dibbling. All plots received 43 kg P_2O_5 as triple superphosphate at sowing. Nitrogen was applied in the form of urea with the second irrigation.

For total N determination, plant samples were washed and separated into different plant parts (namely roots, straw and seeds). After oven drying at 80 ºC for 24 hrs, their weight was taken and then were ground. Total nitrogen contents were determined using the modified kjeldahl method (Cottenie *et al*., 1982).

Data were collected on grain yield, biomass, nitrogen use efficiency (NUE, as described by Moll *et al*., 1982), response ratio and total nitrogen uptake. Data were subjected to standard analysis of variance.

Results and discussion

Reduced irrigation significantly reduced grain yield. The tested genotypes Condor and Elneilain, showed no significant differences in grain yield. Under normal irrigation grain yield significantly responded to increased N application up to the recommended dose (86 kg N ha^{-1}), while under limited soil moisture no significant increase was found beyond 43 kg N ha^{-1}. The results were in agreement with previous reports (Khalifa, *et al*., 1977; Ali, 1981; and Gorashi, 1990).

The interactions

Grain yield of both genotypes, at all N levels was better under normal irrigation and increased with increasing N levels. Under limited irrigation grain yield responded positively up to 65 kg N ha^{-1}, and then decreased with increasing N rates (Fig 1). It is noteworthy that the grain yields achieved at 43 and 65 kg/ha were not significantly different. The significance of this interaction clearly shows the differential response of plants under different water regimes to N fertilizer. More response was found under optimum irrigation regimes and less N fertilizer is needed under water stress conditions.

Latiri-Soki *et al*. (1998) reported that, irrigation and N increased dry matter production and grain yield. They suggested the increase might be due to increased leaf area index (LAI), green spikes area and an increase in the period for which the crop remained green which resulted in increased capture efficiency of radiation energy and consequently more dry matter production. It was also found that, fertilizer

N responses are directly related to the status of soil moisture conditions (Ryan *et al.*, 1991; Campbell *et al.*, 1993a; Pala*, et al.*, 1996).

Nitrogen use efficiency was found to be greater when supplemental irrigation was applied. The present results showed that, under normal irrigation, the response curve was linear and the gain in grain yield was 14 kg kg^{-1} N (Fig 1), while under water deficit the response curve was quadratic and the gain in grain yield was 11 kg/kg nitrogen.

The calculated response ratio (RR) i.e. the increase in grain kg^{-1} of applied N was shown in Table 2. The results showed that in both irrigation regimes, the highest response ratios were obtained with application of 22 kg N ha^{-1}, thereafter, the ratios followed a descending trend. This result was in accord with the result of Dulfera *et al.*(1992). Nitrogen use efficiency (NUE) was defined by Moll *et al* (1982) as grains produced per unit of available N (soil + fertilizer or as fertilizer N). In our experiments, NUE was calculated as grain production per unit of applied N fertilizer. Table 2, showed that NUE was found to decrease with increasing N level. Under limited irrigation, NUE was reduced to approximately half its values under normal irrigation.

Decreased NUE was often observed with increasing N application in other studies (Caldwell and Sturratt, 1987; Campbell and Davison, 1979; Fredrick and Marshal, 1985; Pearman *et al.*,1977). Campbell and Davison (1979) suggested that, inefficient use of N is associated with increased stress induced by excessive vegetative growth. Part of the decrease in NUE can be attributed to decreased light intensity or increased evapotranspiration that could result from excessive vegetation (Pearman *et al.*, 1977).

Nitrogen uptake

As expected increasing N application resulted in a consistent significant increase ($P<0.001$) in crop total N-uptake (Fig 2). However, moisture stress remarkably decreased N-uptake by both varieties. Under zero N treatment, average uptake of N was 39 kg ha^{-1}, indicating that, the soil supplied that quantity of N through uptake from residual mineral N, and mineralized organic nitrogen. The increases in wheat total N uptake with application of N fertilizer have been reported by many researchers (Ibrahim, 1989; Brian *et al.*1995; Olson 1980; and Eck, 1988). The reduction in total N uptake under moisture stress was attributed to decrease in nitrate reeducates activity (Younis *et al.*, 1965; Huffaker *et al.*, 1971; Brain *et al.,* 1975 and Eck, 1988). This reduction in nitrate activity resulted in a decrease of incorporation on ^{15}N into protein. Mustafa and Abedelmagid (1982) showed that as the irrigation intervals was increased the crop was subjected to high water and osmotic stresses and to reduce nutrient uptake. These stresses would be expected to decrease N uptake and its utilization by the crop , inhibit cell elongation and depress photosynthesis. All these effects would undoubtedly, reduce plant height, leaf area index (LAI) and thus forage yield. Conversely, normal watering increased total nitrogen uptake and consequently plant growth Feigins *et al* (1982).

Conclusions

1. When water is not limiting, high rates of fertilizer N (129 kg N ha^{-1}) were found beneficial to plant growth. However, under soil moisture stress, increased fertilizer application will induce rapid plant growth which will enhance the rate of evapotranspiration and the depletion of limited soil moisture and consequently results in reduced dry matter production.

2. Under moisture stress treatment, grain yield was depressed and increasing N fertilization failed to increase grain yield significantly beyond 43 kg N ha^{-1}.
3. Water is a more limiting factor than N fertilizer for wheat production under hot dry environment. Only half the recommended N dose is adequate in areas of known irrigation problems.
4. Wheat under adequate irrigated treatments used N fertilizer more efficiently than under stressed ones.
5. Both N application and frequent watering enhanced total N uptake by wheat.

Recommendation

It is recommended to use only 43 kg N ha^{-1} in wheat production areas of known irrigation problems. This dose of nitrogen can meet directly the economic beneficial evaluation.

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Table 1. Soil characterization of the experimental site at the Gezira Research Farm

Soil classification (soil survey staff (1999)	Chromic, Haplusterts, fine, smect, isohy, El Remeitab soil series none sodic phase.
Nature of parent Material Origin	Blue Nile, Alluvium
Current land suitability subclass	Moderately suitable land due to vertisolic and chemical fertility limitations (S2vf)
Physical characteristics	
% clay	54
Air dry bulk density (gm cm^3)	1.71
Coefficient of linear extensibility (COLE)	0.14
Hydraulic conduct. (H.C; cm hr-1)	0.24
Wetting front (cm)	25
AWC; cm H_2O)	
0-30 cm	6.24
30-120 cm	
	19.84
Chemical characteristics	
% $CaC0_3$	3.7
Ece (dS/m)	0.7
0-30 cm	3.7
30-120 cm	
ESP	6
0-30 cm	12
30-90 cm	
PH-Paste	8.1
O.C.	0.360
%N	0.039
Available – P mg P/kg. Soil	2
Ext. K cmol(+)kg. Soil	0.89
CEC cmol(+)kg. Soil	54
Soluble Anions meq/L.	
$S0_4^{-2}$	0.8-74.2
No_3^{-1}	2.1-11.5

Table 2. Nitrogen use efficiency (NUE) and response ratios (RR) of grain yield to increased N application under two irrigation regimes (avg. of two seasons 1997-98 and 1998-99)

N level (kg ha^{-1})	NUE		RR	
	Normal	Stress	Normal	Stress
22	85	53	25	19
43	54	34	23	13
65	40	25	20	11
86	34	18	19	8
108	29	13	17	5
129	24	11	14	4

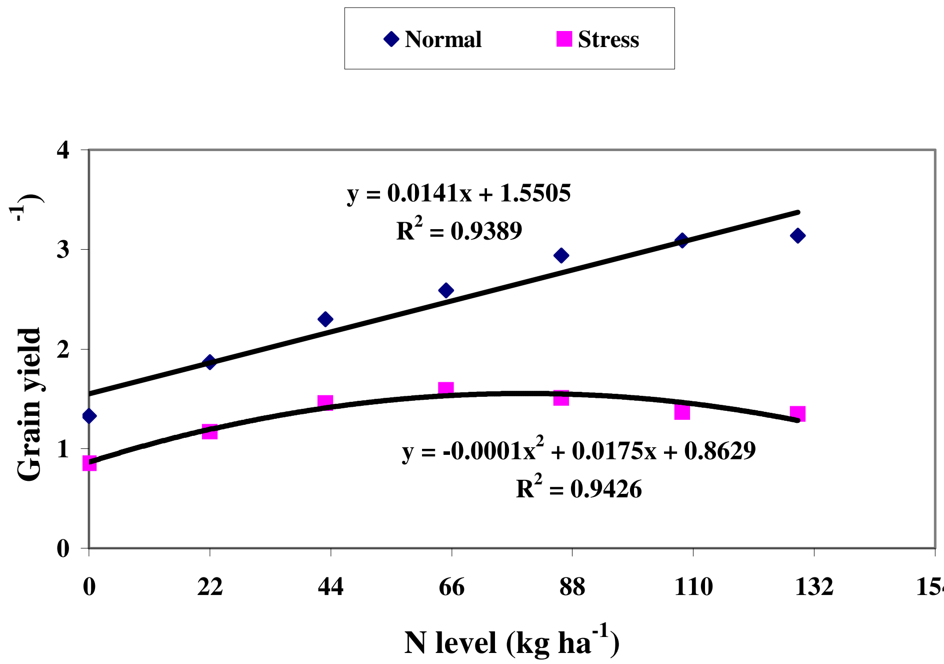

Fig 1: Grain yield response to N level under two irrigation regimes (avg. 2 seasons 1997/98 and 1998/99)

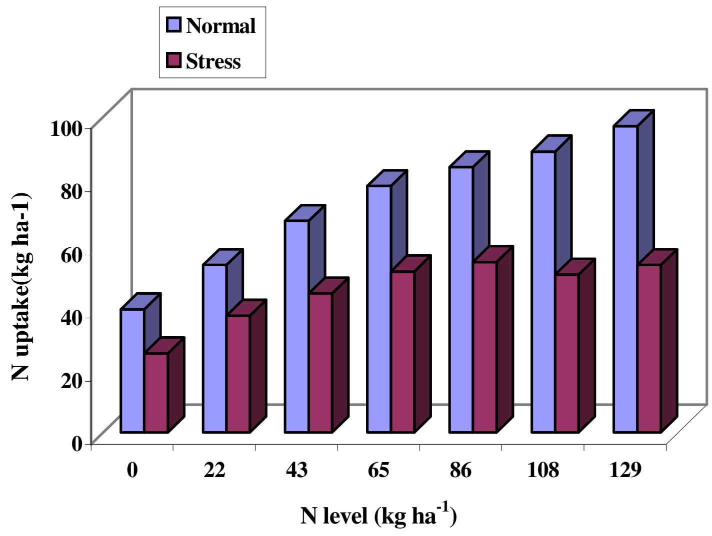

Fig 2: Total N uptake by wheat grown under two irrigation regimes as affected by N rate (avg. of 2 seasons 1997/98 and