Water-Nitrogen Relationships for Wheat Growth and Productivity in Late Sown Conditions

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ABSTRACT

Field experiments were conducted on a sandy loam soil (Typic Ustochrept) to study the water-nitrogen-yield relationships of late sown wheat under adequate and limited water supply conditions. The treatments comprised of four levels of irrigation (I_0, no post-sown irrigation; I_1, one irrigation at CRI stage; I_2, two irrigations, each at CRI and flowering stages; I_3, four irrigations each given at CRI, jointing, flowering and dough stages) in main plots and a combination of three N levels (0, 50 and 100 kg N/ha) and two levels of zinc as $ZnSO_4 \cdot 7H_2O$ (0 and 5 kg Zn/ha) in sub-plots of a split plot design and were replicated three times. Progressive increase in irrigations from 0 to 4 and nitrogen levels from 0 to 100 kg/ha, increased the average LAI, CGR, RGR and NAR, yield attributes, wheat biomass and grain yield significantly ($p \leq 0.05$) over the control (I_0 and N_0), in both the seasons, respectively. Analyses by multiple regression techniques reveled that LAI estimates with N uptake were much higher at 84% predictability than the estimate based on water use that could account for 75% of the variations only. Lower levels of water consumption by crop were seen to result in less leaf area therefore, resulting in lower biomass and grain yields at lower levels of irrigation. The highest rate of biomass gains of 53.1 kg/ha-mm was obtained during the 60–90 day period, a period that fell within the maximum growth phase of wheat, followed by 28.3 and 6.7 kg/ha-mm during 90-120 and 0-60 days after sowing (DAS) periods. The response of the above ground biomass to nitrogen uptake was higher (76.6 kg/ha-kg N uptake) during 60-90 DAS period than during the 0-60 DAS period (22.1 kg/ha-kg N uptake). Additive production functions therefore, took care of the stage sensitivity along with the complete water and nitrogen stresses as induced through different applications of water and nitrogen. The maximum growth rates in wheat were commensurate with highest levels of water use as well as nitrogen use observed during the 60-90 DAS period of growth. For this reasons, scheduling of water and nitrogen application ought to consider providing relatively less quantities of

water during the 0-60 DAS period as compared to the 90-120 and 60-90 DAS periods respectively, in order to provide just sufficient amounts of water so as to enhance the uptake of available nitrogen required for optimum growth and development of wheat.

1.0 INTRODUCTION

Water-Nitrogen relationships or production functions are considered as useful tools in the management of water and nitrogen application for optimization of crop productivity. Crop production functions that relate water-yield or water-nitrogen relationships are mathematical equations relating crop response in terms of biomass or grain yield with water and plant nutrient availability or it's uptake by the crop. These functions can be used in managing water resource for achieving maximum returns with minimum amount of water application as irrigation (English and Raja, 1997). When evaluating dry matter production, expansive growth deserves special attention, since it is the means for developing leaf area for intercepting light and carrying out photosynthesis (Davis, 1994). Maximum (leaf area index) LAI for wheat is generally noticed at anthesis, a time that falls just after maximum growth rate of crop. LAI at flowering is mainly used for forecasting wheat yields, with the prime assumption that there is no stress in the subsequent stages of crop growth. The response of wheat growth rates varies with time of growth, availability of added inputs and environment and is limited by the inherent genetic potential of the crop (Singh *et al.*, 1987; Zhang *et al.*, 1999). Wheat is normally sown in the months of October and November, but may delay due to the harvesting of a previous crop such as rice. Further delays may result from the difficulty to prepare the land and lack of sufficient labour and necessary machinery. Due to these farmers plant late in the months of December or January. The choice of a suitable cultivar is therefore of paramount importance for purposes of realizing optimum yields commensurate with added inputs. An experiment was therefore carried out to evaluate and relate the influence of irrigation, nitrogen and Zinc on the growth and productivity of wheat, with the aim of determining crop water use and nitrogen uptake relationships under late sown conditions. The project took three years.

2.0 MATERIALS AND METHODS

A field experiment was conducted on a sandy loam soil at the Water Technology Center, Indian Agricultural Research Institute, New Delhi during *rabi* (winter) 1999-2000 and 2000-2001, situated at $28^0 38'$ N latitude, $77^0 11'$ E longitude and 228.6m altitude. The soil of the field was sandy loam (Typic Ustochrept) having low available N, medium available phosphorus and potassium with pH 7.5. Plant available water was 18 cm /120 cm root zone profile. Treatments comprised of four levels of irrigation levels (I_0, no post-sowing irrigation; I_1, one irrigation at (crown root initiation) CRI stage; I_2, two irrigations, each at CRI and flowering stages; I_3, four irrigations each given at CRI, jointing, flowering and dough stages) in main plots. A combination of three N levels (N_0–0, N_{50}- 50 and N_{100}-100 kg N/ha) and two zinc levels (Z_0-0, and Z_5-5 kg/ha) in the sub-plot of a split plot design, that was replicated thrice. Wheat cultivar HD 2285 was sown on 22nd and 13th of December and harvested on 21st and 15th April of the seasons 1999-00 and 2000-01, respectively. Phosphorus ($P_2 0_5$) and potassium ($K_2 0$) were applied during sowing time, through single super phosphate and muriate of potash uniformly as basal dressing at the rates of 60 and 40 kg/ha, respectively. Nitrogen and zinc were applied as per treatment through urea and $ZnS0_4.7H_2 0$, at sowing time. The crop was seeded at the rate of 120 kg/ha, 25 cm apart in plots measuring 3m x 5m (gross). The crop received 76.8 mm and 42.6 mm rainfall in the respective seasons. Irrigation schedules were done on the basis of the critical growth stages of the crop as per treatment by flood irrigation method through channels. The measured depth of irrigation water was applied through a partial flume (7.62cm) as per treatment. Ground water remained below 4.0 m throughout the growth period and there was no ground water contribution. Moisture extraction was determined gravimetrically. Production functions were worked out by multiple regression analysis techniques, where the independent variables were the inputs: viz. water, nitrogen, and their uptake i.e., evapotranspiration (ET) and N-uptake, respectively. The dependent variables were LAI, above ground biomass, height, grain yield, and the yield attributes (tillers/m^2, ear length, grains/ear and the test weight).

3.0 RESULTS AND DISCUSSION

3.1 Effect of Irrigation on Growth

The LAI estimates based on water use (Fig. 1a) could account for 75% of the variations only as given in equation 1 below.

Y = -0.271+0.097*x-0.0004*x2, R2 =0.75 .... (1)

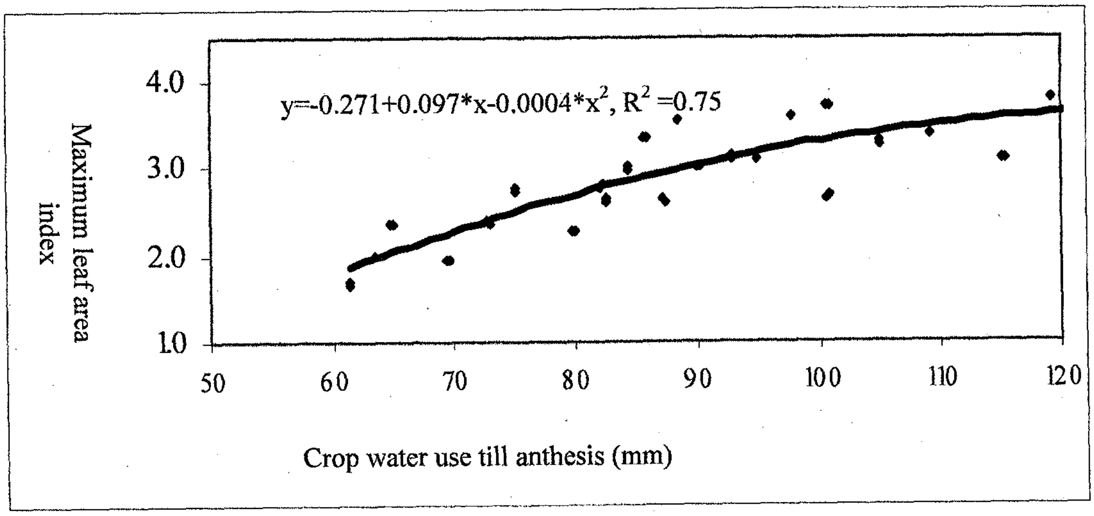


Figure 1a: **Relationship of leaf area index at anthesis with respective water use for wheat**

Lower levels of water consumption were seen to result in less leaf area (Fig. 1b), therefore resulting in lower above ground dry matter production (DMP) and grain yields at lower levels of irrigation (Fig. 7b). This corroborates the findings of Vaux and Pruitt (1983) who stated that the sensitivity of expansive growth to small water deficits is marked by reduction in leaf area.

Final biomass and grain yield of wheat depend upon the sensitivity of phyto-phases to moisture availability where scheduling of irrigation is exercised. Dated production functions take care of the crop stage sensitivity and thus gives better predictability for biomass and yield estimates (Kalra, 1986; Singh *et al.*, 1987). The highest rate of biomass gains of 53.1 kg/ha-mm was obtained during the 60–90 day period, a period that fell within the maximum growth phase of wheat, followed by 28.3 and 6.7 kg/ha-mm during 90-120 and 0-60 days after sowing

(DAS) periods respectively (Fig. 3). This was in agreement with the findings for semi arid regions of Hisar (Singh *et al.*, 1987) and in China (Zhang *et al.*, 1999).

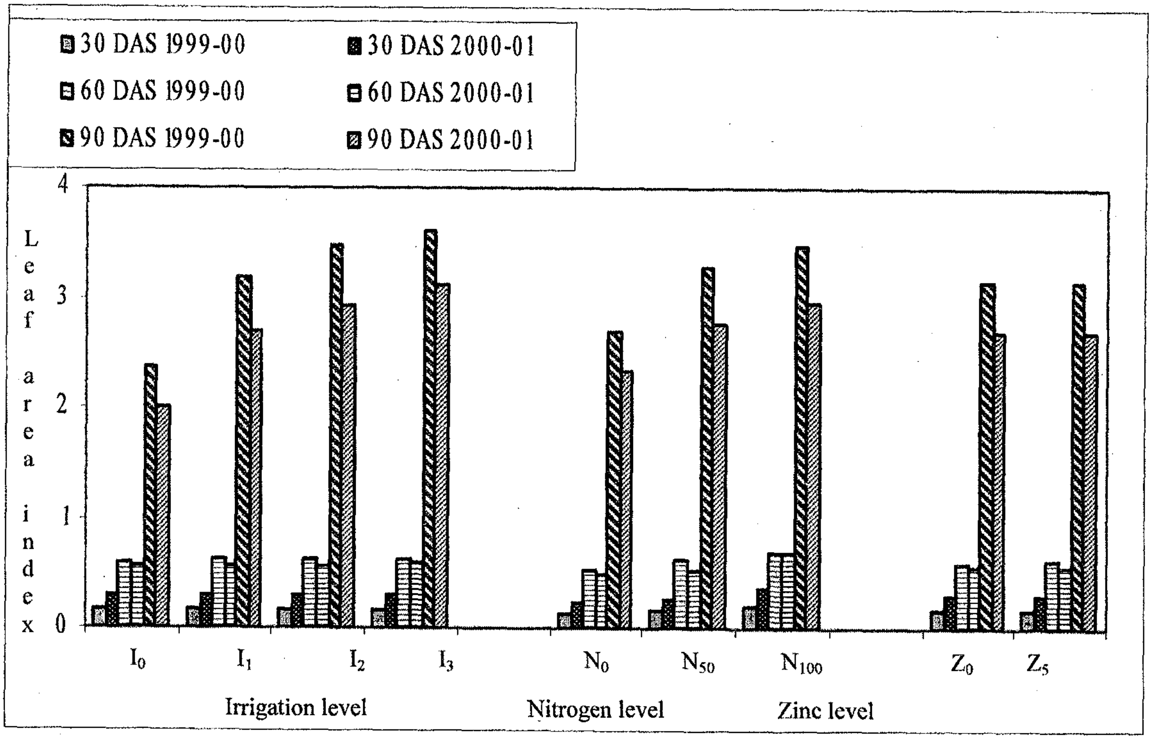


Figure 1 b: Influence of irrigation, nitrogen and zinc on the leaf area index at different stages of growth in late sown wheat

With respect to the amounts of water requirement, it may be deduced that 0-60 DAS period was the least important due to the comparatively lower rates of increase in dry matter production (DMP) as compared to the other phases of growth. Its importance, however, was realised later as the crop matured and the growth was compounded in the subsequent stages of growth, more so in the grain filling stage. The period of 60-90 days was a phase associated with high crop growth rates (CGR) and relative growth rates (RGR) (Fig. 5 and Fig. 6). This period however, had few developmental phyto-growth (phasic) stages as compared to the 0-60 days period (where wheat developed through the crown root, panicle and tiller initiation phases), which are considered to be critical in realising the final economic yield, so long as there were no limiting factors such as water and nutrients.

3.2 Effect of Nitrogen on Growth

The LAI estimates with N uptake were much higher at 84% predictability (Fig. 2 and Eqn. 2) than the estimate based on water use (Fig. 1a and Eqn. 1) that could account for 75% of the variations only.

Y = -0.445+0.059*x-0.0002*x2, R2 =0.84 .... (2)

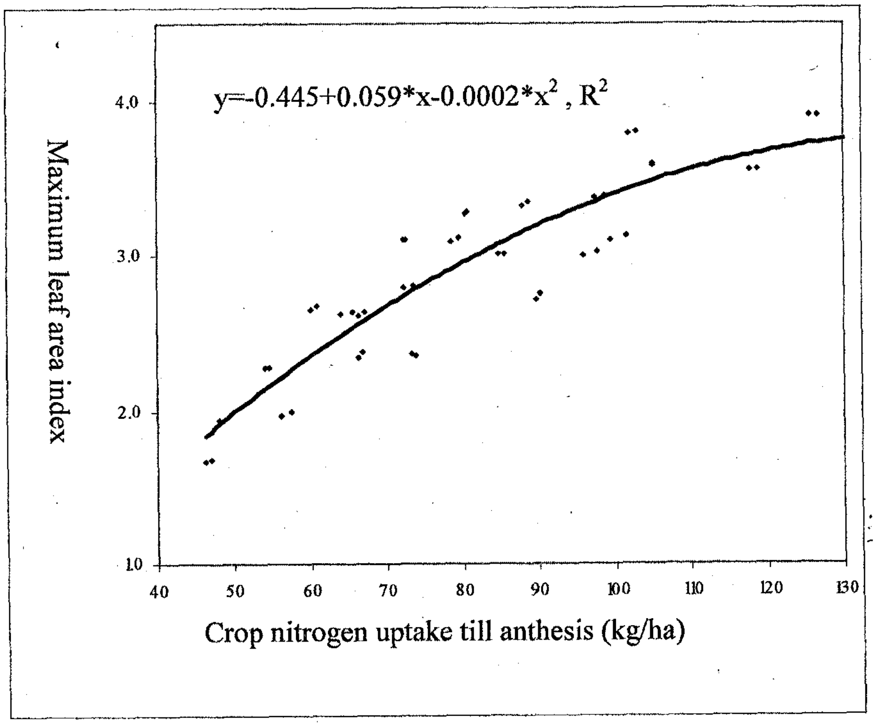


Figure 2: Relationship of leaf area index at anthesis with the respective crop nitrogen

The response of the above ground biomass to nitrogen uptake (Fig. 4) was higher (76.6 kg/ha-kg N uptake) during 60-90 DAS period than during the 0-60 DAS period (22.1 kg/ha-kg N uptake). The period between 60-90 DAS was considered as a period of maximum growth rate in terms of CGR (Fig. 2) and RGR (Fig. 3).

Nitrogen application and thus uptake increased LAI (Fig. 2), CGR (Fig. 5), RGR (Fig. 6), plant height (Fig. 9) and ultimately total biomas and grain yield (Fig. 7). Thus, with adequate supply of N, the crop produced more leaf area and higher growth rates which consequently resulted into higher biomas and grain yields of wheat in both seasons. Nitrogen being a constituent of amino acids, protein and protoplast, would directly influence plant growth and development through better utilization of photosynthates up to a certain level depending on the genetic potential of the crop and soil N availability.

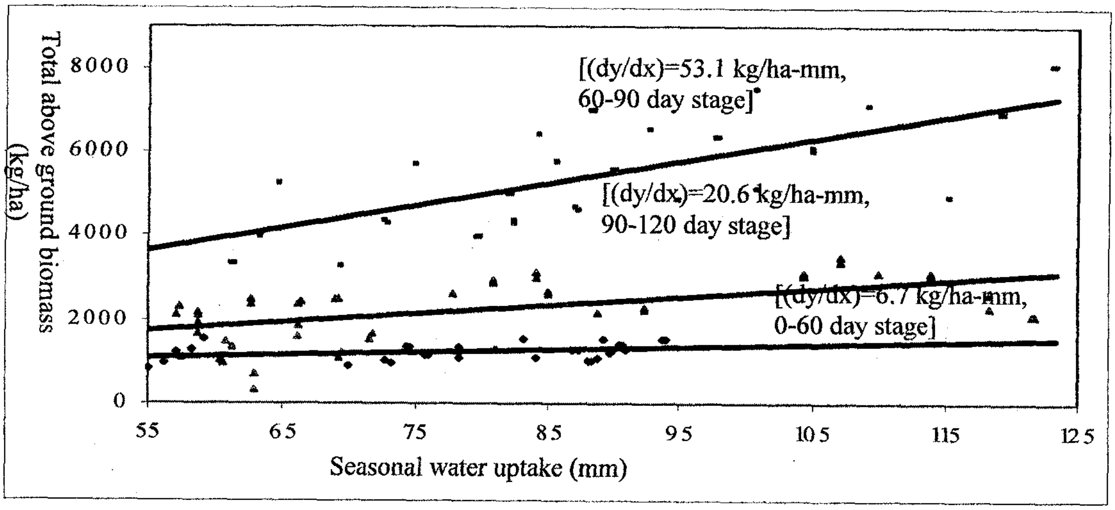


Figure 3: Above ground biomass gains at various crop growth stages for wheat as related to respective water use

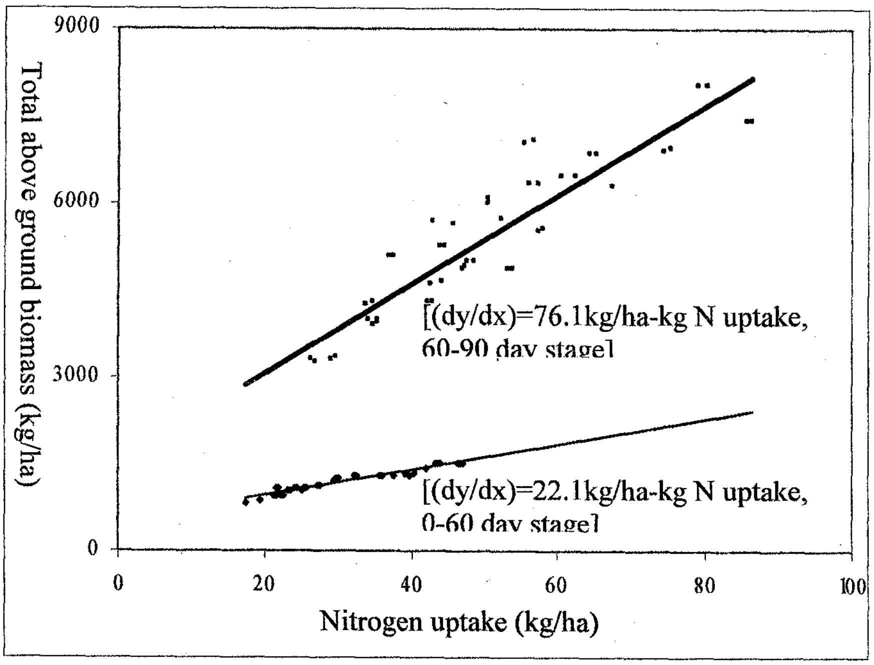
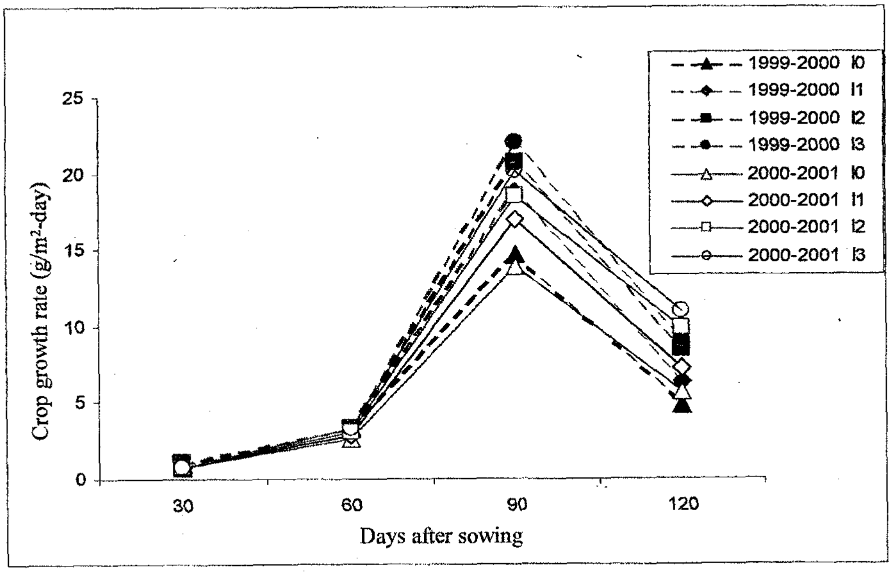


Figure 4: Above ground biomass gain in various crop growth stages for wheat as related to respective nitrogen uptake

Under higher N fertilization, more DM was also partitioned into leaves, which expanded rapidly and intercepted greater portion of insolation which resulted in higher photosynthetic activity and biomas (Davis, 1994).



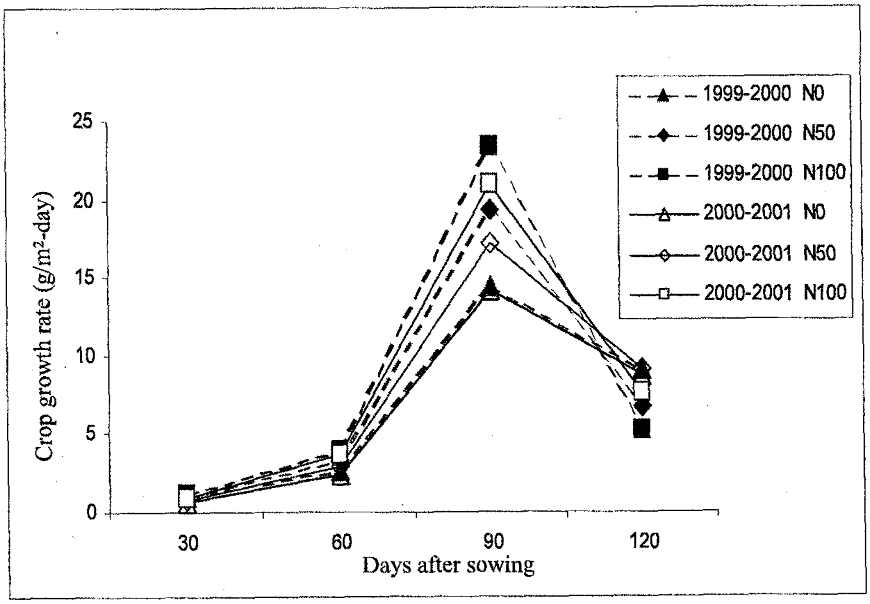


Figure 5: Influence of irrigation and nitrogen on the CGR (g/day/m^2) of the late sown wheat at 30, 60, 90 DAS and at harvest

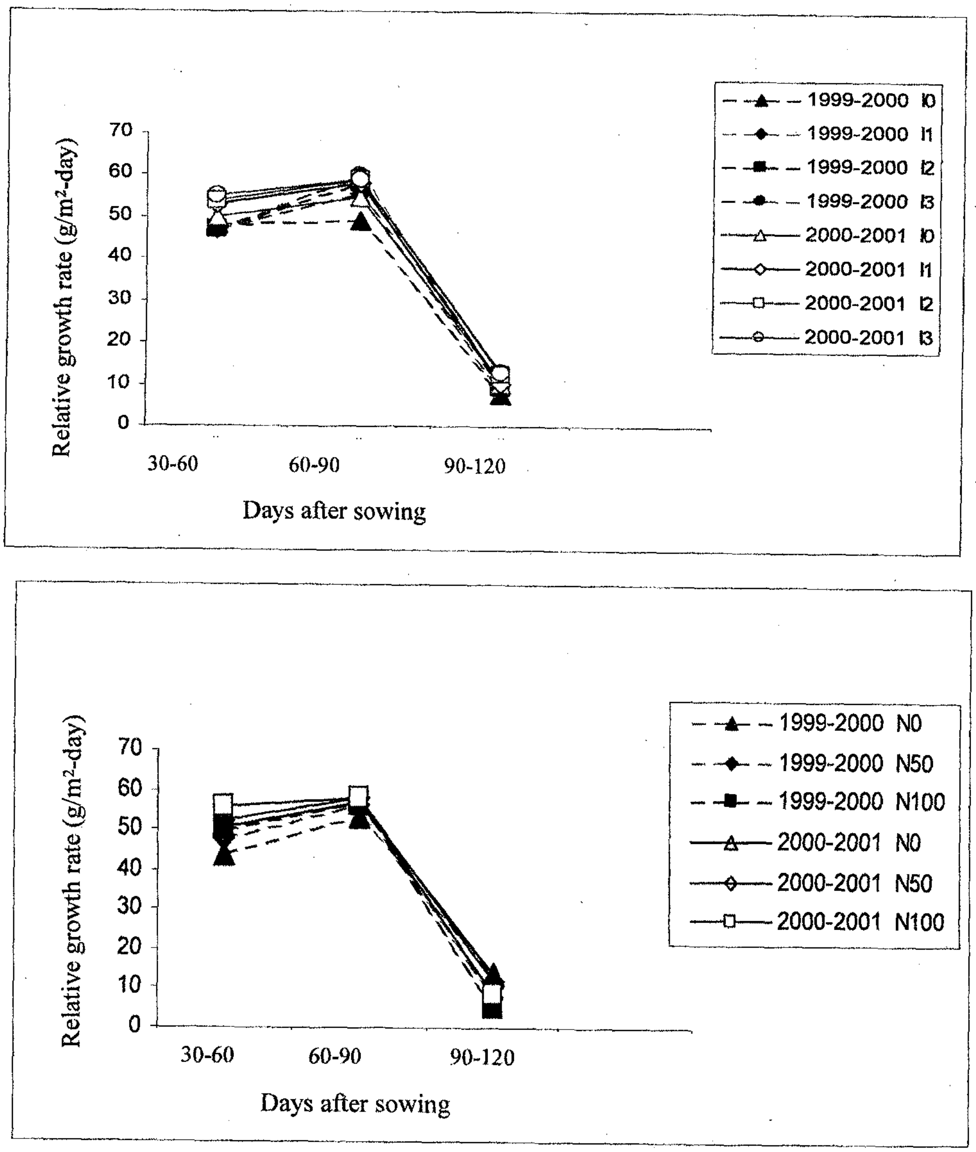


Figure 6: Influence of irrigation and nitrogen on the RGR (mg/g/day) of late wheat at 30-60, 60-90 & 90 DAS to harvest

3.3 The Synergy of Irrigation and Nitrogen Interaction

The maximum growth rates in wheat were commensurate with highest levels of water use (Fig. 3) as well as nitrogen use during 60-90 days period of growth. Thus, crop nitrogen uptake within a particular duration depended upon the extent of water and nitrogen applied. Therefore, the additive production functions took care of the stage sensitivity along with the complete water and nitrogen stresses as induced through different applications of water and nitrogen. The phase between 0-60 DAS is associated with slower growth rates and thus, lower water and nitrogen requirement. For this reason, scheduling of water and nitrogen application ought to consider providing relatively less quantities of water during the 0-60 DAS period as compared to 90-120 and 60-90 days periods, respectively. This would provide just sufficient amounts of water so as to enhance the uptake of available nitrogen by wheat for optimum growth and development.

The maximum response by wheat growth attributes (LAI, CGR and RGR) and yield to irrigation and nitrogen interactions was most pronounced at the 90 DAS, and under the maximum irrigation (I_3) and nitrogen (N_{100}) treatment levels. The availability, uptake and utilization of N by plants increases with increase in soil moisture supply up to a near optimal level, which increases greater root development besides faster mass transportation of NO_3-N in the soil surface (Nye and Tinker, 1977). Therefore, the compounding effects of the growth affecting factors, namely, nutrient N, soil moisture and insolation, culminates in a maximum crop growth period and has a profound effect on the cumulative biomas and ultimate grain yield production of wheat.

3.4 Effect of Water and Nitrogen Uptake on Wheat Productivity

The effectiveness of water use towards yield benefit tended to increase with the amounts of nitrogen uptake (Fig. 7) by the following functions given below:

y = 4.003+ 0.065*x-5E-05*x2, R2 = 0.94 (biomass) ....(3)

y = 0.84+ 0.032*x-2E-05*x2, R2 = 0.95 (grain) .... (4)

Crop N uptake is generally decided by the amount of water and nitrogen applied to the crop because nitrogen uptake is dependent on the mass flow of soluble nitrates in the soil. Therefore, nitrogen uptake was found to be a better predictor of both biomass and grain yield harvests (Fig. 7). The second degree quadratic curves accounted for 94 % and 95 % variations, respectively, compared to 75 % and 73 % when the crop ET/pan evaporation ratio was related with biomass and grain yield, respectively (Fig. 8). This was in agreement with Vaux and Pruit (1983).

$y = -4.951+41.22x-26.62*x^2$, R2=0.75 .... (5)

$y = -3.3+19.29x-12.284*x^2$, R2=0.73 .... (6)

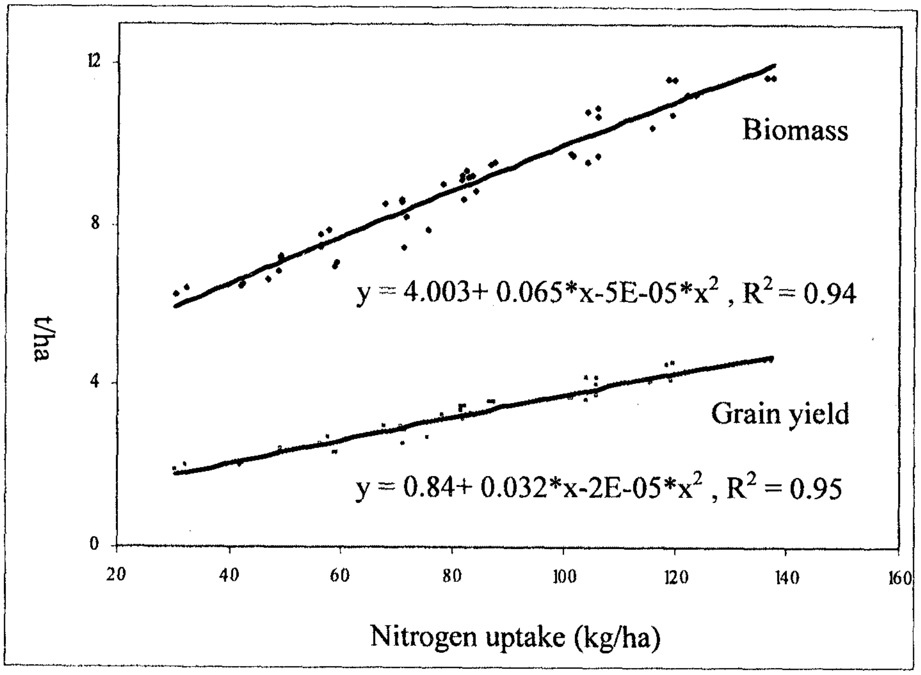


Figure 7: Relationship of above ground biomass and grain yield to seasonal nitrogen uptake under different water and nitrogen application treatments for wheat

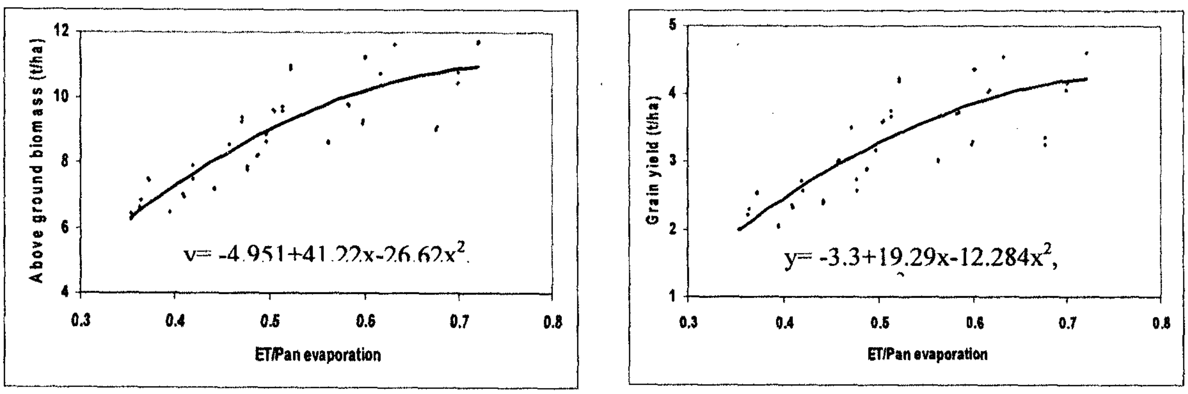


Figure 8: Above ground biomass and grain yield of late sown wheat as related to the ratio of seasonal evapo-transpiration to seasonal pan evaporation

3.5 Effect of Water and Nitrogen use on Yield Attributes

Height (Fig. 9), effective tiller/metre row length, number of grain/ear (Fig. 10), ear length and 1000 grain weight (Fig. 11) were found to increase with increase in water and nitrogen uptake by late sown wheat.

Computed height (cm)= 0.0541*ET(mm)+0.1793*Nup (kg/ha) +41.3

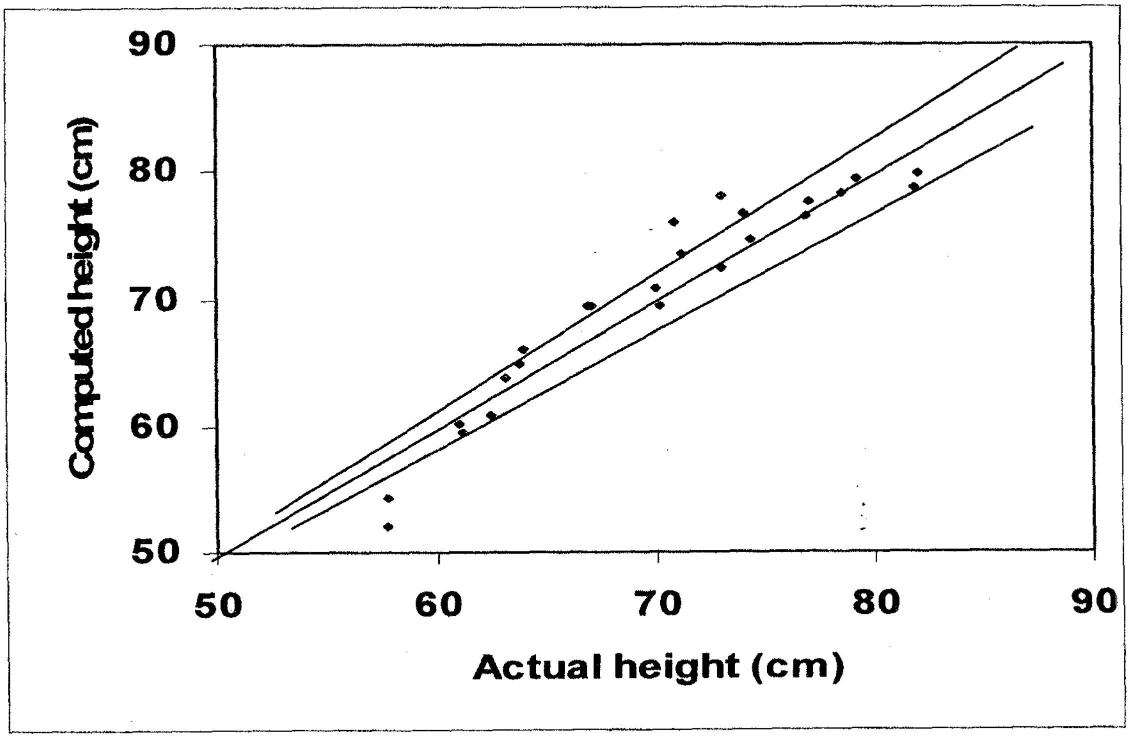
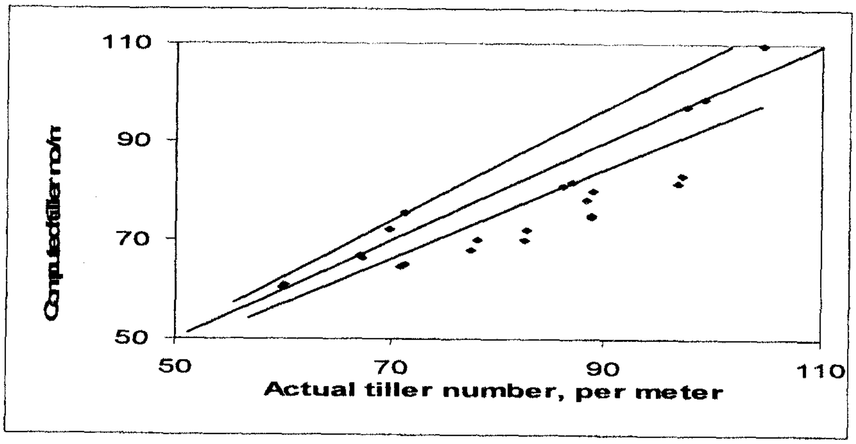
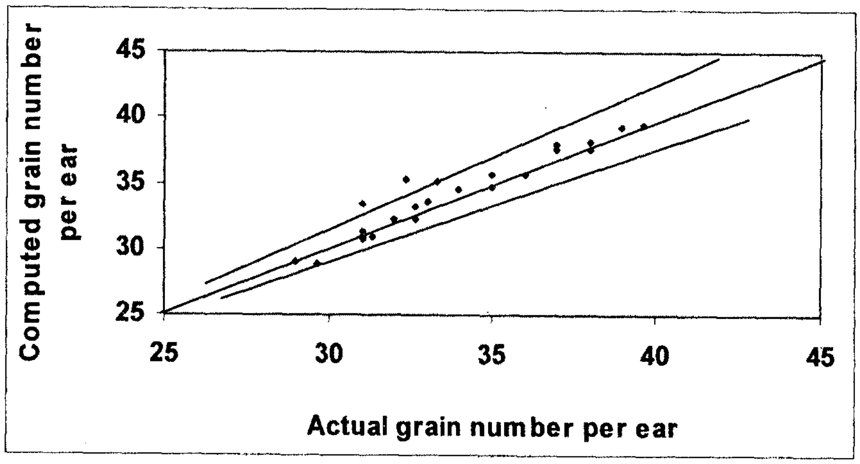


Figure 9: Comparison of computed and actual height of late sown wheat, as affected by evapo-transpiration and nitrogen uptake (validation with second year data set)

The first season (1999-2000) data set of seasonal water consumptive use and seasonal N uptake were regressed with the respective yield attributes then the functions were used to compute the respective attributes using the second season (2000-2001) data of water and N uptake. When the computed yield attributes were plotted against the actual second seasons attributes and a 1:1 line drawn, the functions were found to be within acceptable limits.



Computed Tiller number (no./m)=0.0644*ET(mm)+0.3933*Nup(kg/ha)+33.94



Computed Grain number/ear=-0.0111*ET(mm)+0.1356*Nup(kg/ha)+26.5

Figure 10: Comparison of computed tiller no./m row and grain no. per ear as affected by evapo-transpiration and nitrogen uptake in late sown wheat (validation with second year data set)

The scatter points were found to lie within 10 % error margin for all yield attributes except the estimates of ear length which were generally over estimated by the mechanistic functional equations obtained (as given below).

Computed height (cm) = 0.0541*ET(mm) + 0.1793*Nup (kg/ha) + 41.3 .... (7)

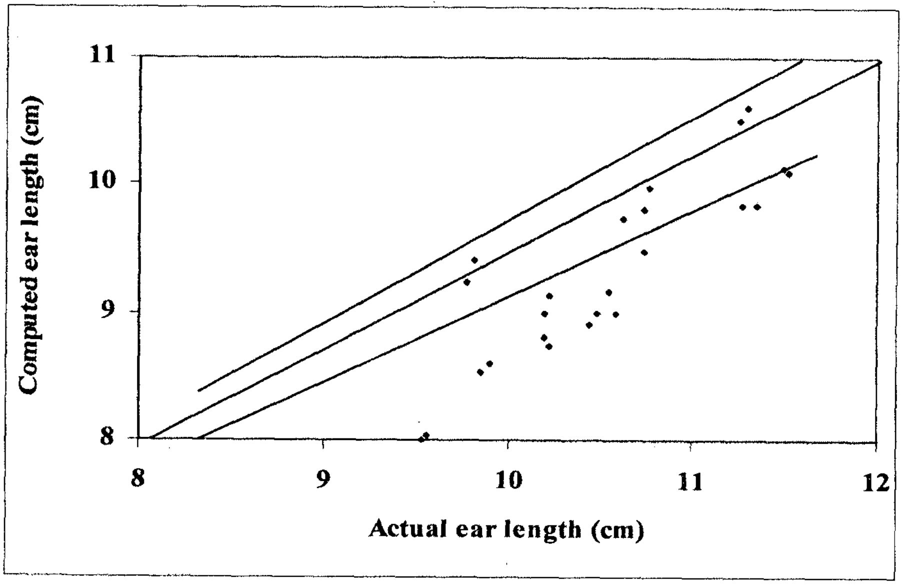
Computed Tiller number (no./m) = 0.0644*ET(mm) + 0.3933*Nup(kg/ha) + 33.9....... (8)

Computed Grain number/ear = -0.0111*ET(mm)+0.1356*Nup(kg/ha) + 26.5.... ..... (9)

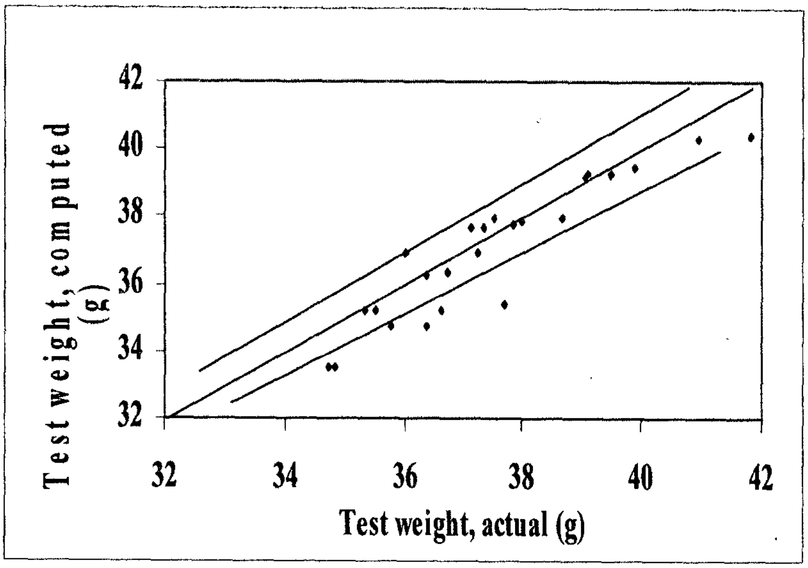
Computed Ear length (cm) = -0.0133*ET(mm) + 0.0405*Nup(kg/ha) + 10.6............ (10)

Computed Test weight (g) = 0.00616*ET(mm) + 0.0656*Nup(kg/ha) + 30.1 .. .. (11)

Wheat growth attributes were observed to increase as described by the above mentioned seasonal water use and crop nitrogen uptake, additive production functions. These functions enable us determine the cumulative degree of contribution of each factor, i.e., water and nitrogen uptake, towards the yield attributes under study. Arnon (1972) noted that so long as other factors are not limiting, irrigation at CRI, jointing, flowering and doughy stages of wheat, normally enhances tillering, growth rates and grain filling respectively. Stimulatory effects of N on tillering through cytokinin synthesis are known to result into more number of effective tillers of wheat (Gardner et al., 1988). Therefore, during heading to flowering stages of wheat, the assimilates produced by photosynthesis is normally more than required by these processes when inputs like nutrients and water are adequate. At the time of grain filling, assimilates remobilize from leaves and stems (source) to grain (sink) if photosynthesis is not able to furnish the assimilate requirement of grains. Increased growth rates and leaf area indices due to increase in nitrogen and water availability would thus, result in higher accumulation of photosynthates in ears of wheat, thereby increasing the length of ears and test weight of wheat. This is in agreement with Davis (1994) and Kang *et al.* (2002). Further study on dated (i.e., stage-wise growth studies) -additive production functions would further shed light on the crop responses to inputs at specific crop stages and therefore enable us make better nutrient and water management decisions.



Computed Ear length (cm)=-0.0133*ET(mm)+0.0405*Nup(kg/ha)+10.6



Computed Test weight (g)=0.00616*ET(mm)+0.0656*Nup(kg/ha)+30.1

Figure 11: Comparison of computed and actual ear length and test weight as affected by evapo-transpiration and nitrogen uptake in late sown wheat (validation with second year data set)

4.0 CONCLUSIONS

Lower levels of water consumption were seen to result in less leaf area, therefore, resulting in lower above ground dry matter production and grain yields. The LAI estimates with N uptake were much higher at 84% predictability than the estimate based on water use that could account for 75% of the variations only. Nitrogen application and thus uptake increased LAI, CGR, RGR, yield attributes and ultimately total biomas and grain yield. Therefore, with adequate supply of N, the crop produced more leaf area and higher growth rates, which consequently resulted into higher biomas and grain yields of wheat. The maximum growth rates in wheat were commensurate with highest levels of water use as well as nitrogen use during 60-90 days period of growth. Thus, crop nitrogen uptake within a particular duration depended upon the extent of water and nitrogen applied. Therefore, the additive production functions took care of the stage sensitivity along with the complete water and nitrogen stresses as induced through different applications of water and nitrogen. Increasing irrigation and nitrogen availability resulted in taller plants, higher tiller number/ meter row length, grain number/ear, ear lengths and test weights of wheat. It is evident that though seasonal production functions are helpful in relating crop responses to inputs, dated production functions that have an additive function would help provide further information on the degree to which the crop is sensitive to a particular input over a particular stage of wheat growth.

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