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Effect of Time and Rate of Application of Nitrogen on The Yield of the Mexican Wheat under the Semi-Arid Conditions of Tunisia

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EFFECT OF TIME AND RATE OF APPLICATION OF NITROGEN ON THE YIELD OF THE MEXICAN WHEAT UNDER THE SEMI-ARID CONDITIONS OF TUNISIA

by

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To all my family this work is lovingly dedicated.

Habib M. Halila

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ABSTRACT

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by

Habib M. Halila, Master of Science

Utah State University, 1971

Major Professor: Dr. D. W. James

Department: Soil Science and Biometeorology

The effect of the time and rate of application of nitrogen on the yield of high yielding varieties of wheat was studied under the semi-arid conditions of Northern Tunisia.

Analysis of the experimental data showed that nitrogen increased the yield of wheat in most locations which were chosen for this experiment.

In high rainfall areas, late application of nitrogen (tillering, jointing stages) was more effective than early applications. The optimum yield was obtained by applying 90 kilograms of nitrogen per hectare.

In the medium to low rainfall area, early applications (seeding time) were more effective than the late ones. The optimum yield was obtained by applying 67 kilograms of nitrogen per hectare.

The yields varied from one location to another. This variability was found to be very dependent on the amount and distribution of the rainfall, thus moisture in the soil and the residual nitrogen.

(53 pages)

INTRODUCTION

Tunisia is shaped something like an elongated quadrilateral. It has an area of approximately 50,000 square miles. It lies in the temperate zone, approximately between the thirty-seventh and the thirtieth north latitude and eighth and twelfth east latitude. The Atlas Mountain barrier which runs the length of North Africa from Morocco through Algeria into Tunisia diminishes in altitude as it goes eastward but its summit divides Tunisia into two well-defined regions, a relatively well-watered and fertile Mediterranean north, known as the Tell, and an arid plateau region which starts in the center and becomes a desert in the extreme south as it merges with the Sahara.

The major climatic influences in Tunisia are the Mediterranian and the Sahara. Summers are long and hot; from May through September rain rarely falls. Winters are mild with moderate rainfall, decreasing from the northwest to the southeast. The rainfall ranges between a maximum of 1500 millimeters per year in the mountains of the northwest to a minimum of 150 millimeters per year in the south (Figure 1).

Cereals are the principal product of Tunisian agriculture. The ten year average production of wheat is approximately 550,000 metric tons; two-thirds of the production is durum wheat, the rest being tender (bread) wheat. The present Tunisian needs are 30,000 metric tons of durum wheat and 450,000 metric tons of bread wheat. Aware of this deficit between needs and production, the Tunisian officials have created a project for the increase of cereals production whose goal is to import and promote new high yielding varieties which have been developed in Mexico by Dr. Borlaug and his team.

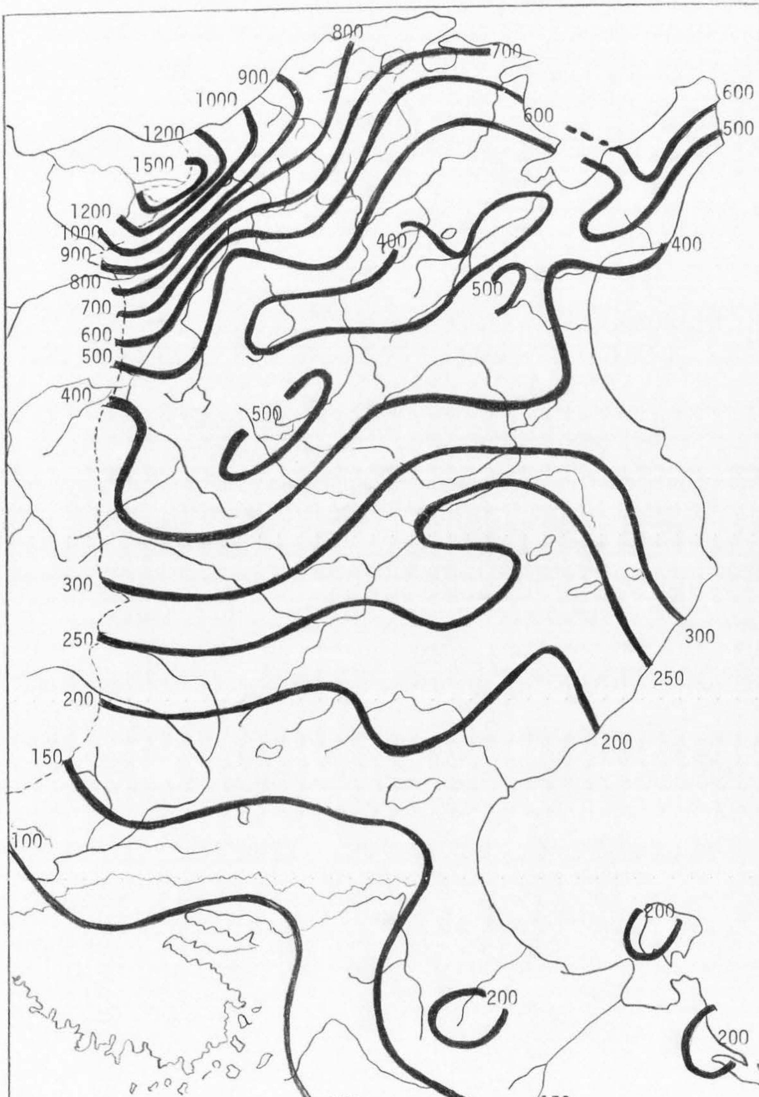

Figure 1. Rainfall distribution based on 30 year average in mm.

These Mexican varieties were introduced into Tunisia in 1967 for simultaneous experimentation and farm demonstration. After preliminary experimental tests for two years by the agricultural research institute and two years of extensive demonstrations, these varieties have shown good adaptability and good resistance to most diseases. In 1969-70, 50 percent of the total soft wheat production was with the Mexican varieties; and these were planted on only 19 percent of the total acreage (ACPP Report, 1968-69). Behind this increase in the production there were two factors:

1. High yielding potential of the new variety
2. An increased use of nitrogen (N) fertilizer.

Parker and Nelson (1966) reported that improved wheat varieties with high yield potential are of little significance unless they are grown on soil that is properly fertilized. Therefore, the necessity for an expanded and accelerated soil fertility and fertilizer use program was brought about by the introduction of these high yielding, fertilizer responsive, semi-dwarf wheat varieties. This fertilizer program represents a major part in a demonstration program. Numerous experiments concerning fertilizer and especially nitrogen requirements of these new varieties were conducted.

The main objective of this thesis is to summarize and analyze the results of these N fertilizer experiments in order to determine as accurately as possible the optimum rates and the proper time of application of N as needed for maximum production.

LITERATURE REVIEW

With an increased use of nitrogen fertilizers and the introduction of the new Mexican varieties, Pakistan raised its wheat production from 4.6 million tons in 1964 to about 8.4 million tons in 1969. Similarly, India increased production from 12 million tons in 1965 to over 20 million tons. Turkey doubled its production of wheat in the spring wheat Mediterranian coastal area over a four-year period. These phenomenal successes have been referred to as "the green revolution" (CIMMYT Report, 1969-70). Behind this so called "green revolution" stands two major factors, the efficient nitrogen use by the high yield potential varieties and an increased awareness of nitrogen fertilizer by the farmer (CIMMYT Report, 1969-70).

These two factors are related to each other. Tisdale and Nelson wrote "under low fertility conditions a given variety may not be allowed to develop the full potential. In fertile soils the new higher yielding variety will deplete the soil more rapidly and yields will be depressed if nutrient supplements are not provided."

In Tunisia many factors have caused the wheat production to be low. They are roughly grouped into two categories--climatic factors and management factors.

In the climatic factors there is the rainfall which is highly variable from year to year, and also during the growing season itself. The management factors include the lack of a fertilizer use program and inadequate farming practices. Some local varieties can produce a relatively high yield if they are fertilized adequately (ACPP Report, 1968-69). Nitrogen as a fertilizer has not been used on wheat extensively, first because of its association with economic reasons and second, because of wheat susceptibility to lodging. The recent development of short stiff-strawed varieties such as Mexican type by Borlaug promises to overcome this difficulty (Hucklesby et al., 1971) and promises to overcome also the problem of low production, providing they are given an adequate amount of nutrient elements. The yield of semi-dwarf varieties with similar characteristics as the Mexican has been found to increase proportionately more than the tall spring varieties and the net profits from the semi-dwarf were nearly double those from tall spring wheats when both were fertilized with N (Woodward, 1966). Similar results have been found by comparing the yield of the semi-dwarf varieties and the local varieties under the same conditions in North Africa (Tunisia, ACPP Report 68 and Morocco, Project Report, 1968-69) and the Middle East (CIMMYT, 1969).

Fuehring (1969) has found that the grain yield of a Mexican semi-dwarf wheat (Pitic 62) when under irrigated conditions, was increased economically by N application (300 kg/ha) up to 9 metric tons/ha. While the N has been agreed on as the major factor in increasing the yield of wheat under favorable precipitation, the time of application is still an argued question. It depends largely on the moisture available in the soil and on the rainfall during the growing season (Leggett, 1959).

Neiding and Snyder (1924) found that a high moisture content in a soil containing sufficient available N results in high yield of wheat with high percentage of protein, while a low moisture content in the soil containing an excess of available N results in a lower yield of wheat but a higher protein content. Jackson, Reisenauer and Horner (1952) found similar results.

A minimum available moisture percentage of about 30 must be maintained in the soil for the production of maximum grain yield under optimum N (Fernandez and Laird, 1959).

Many studies (Leggett, 1959) have been conducted in order to find a correlation between the moisture available in the soil at seeding time, N applied and the yield of the wheat. These studies showed that the amount and pattern of the rainfall during the growing season should be taken into consideration.

Hallstead and Mathew (1936) showed that the depth to which the soil was wet at seeding time has, on the average, borne a very close relationship to the yield obtained but indicated that the soil moisture at planting time became a less reliable basis for predicting crop yields as the annual average precipitation decreased. Brengle and Greb (1963), working in eastern Colorado, found almost similar results but stated that it is impossible to predict the yield of wheat or the response to fertilizer on the basis of soil moisture at planting time.

Based on crop sequence research in the Southern High Plains, Army, Bond and VanDoren (1959) showed that 55 to 66 percent of the variability in wheat yields was attributable to variability in growing season precipitation. Large year-to-year variations in yields occurred because of the variations in amount and distribution of precipitation. When N fertilizer was used, yields were increased over dry-land yields by two bushels per acre inch of irrigation water applied in dry season and two to three bushels per acre inch in a wet season (Jensen and Sletten, 1965).

Leggett (1959), doing the same type of work as Jensen but under dry-land conditions, indicated that four inches of water are required to grow the crop to the heading stage and that each additional inch increased the yield approximately six bushels per acre.

Ramig and Rhoades (1963) demonstrated the importance of moisture at seeding time for assimilation of N by the crop by showing that N recovery increased from 30 to 50 percent as available soil moisture at seeding time increased from 0 to 8 inches. Their results indicated also that the water use and water use efficiency increased as available moisture and rate of N increased.

All the above studies showed clearly the importance of the amount of moisture which must be available to the plant during the growing season and the efficiency with which it is used by the crop. Therefore, care should be taken in order to store in the soil the maximum amount of moisture during the wet season. The amount stored in this manner depends on:

1. The amount of rainfall received
2. The fraction of rainfall that enters the soil
3. The water holding characteristics of the soil.

The only one of these factors over which the farmer has any degree of control is the second, the fraction of rainfall which enters the soil. This fraction can be increased by practices which (1) decrease runoff and erosion, and (2) decrease in the summer the loss of moisture from the soil through evaporation.

Many studies have been undertaken in order to find out which practices are the most effective for many crops. Jones et al. (1969) compared mulched treatments on tilled and non-tilled plots.

They found that the mulched treatments, regardless of the type of mulch, gave the lowest values for runoff and the highest values for soil water content and yield of corn. They also found that the no-tillage with the killed-sod type mulch treatment was the most effective in reducing evapotranspiration.

Moody, Jones and Lillard (1963) reached similar conclusions. They indicated that the available soil moisture of the mulched soil averaged for the three-year experiment 28 percent higher in July and 17 percent higher in August than the bare surface plot.

Smika, Black and Greb (1969) indicated that mulched soils contained more water and less NO_3-N at seeding than bare soils but grain yield responses to added N were greater on bare soil than on mulched soil.

One of the important components governing grain yield is the number of heads produced per unit area which in turn depends on the rate of seeding, rate of emergence, degree of tillering, and on the survival of formed heads. Thus, effects that increase the amount of tillering promote the possibility of reducing the seeding rate, which is important when seed is expensive as with hybrid wheat.

Wahab and Hussein (1957) found that N fertilization at seeding time and under irrigated conditions increased the number of tillers per plant, number of mature heads per plant, number of grains per head, and the yield of grain per acre. Bedinger (USAID/Rabat, 1970) has also found that N applied at seeding time under dry-land conditions gave a good response in plant tillering, whereas N, applied late, did not.

On the contrary, Doll (1962) found that N fertilizers applied to winter wheat at the time of fall seeding are frequently not as effective as top-dressing in the following spring. That was under Kentucky climatic conditions. The addition of N to wheat during the latter growth stages has been observed to increase grain protein but not necessarily yield or test weight (Gericke, 1922). Blacket (1957) attributed a lack of response for fall applied N on wheat to a heavy rain (6.57") prior to germination since a marked response was obtained for spring applications. The split applications in which half the N was applied at seeding and the remainder topdressed in February, resulted in higher yields of rye forage than when all the N was applied at seeding. No rainfall data were reported for these experiments (Morris and Jackson, 1957).

For the N to be most effective, P and other essential elements should be adequate. Various studies have ascertained the influence of adequate nutrients, such as P and N on the amount of tillers. Boatwright and Viets (1966) used solution culture to study P absorption during various growth stages of spring wheat; they found plant development was retarded when P was withheld for the first two weeks of growth.

In a field study with spring wheat Boatwright and Haas (1961) found that when P was limiting N uptake may continue until the soft dough stage of grain development. They found also that the N content of grain was derived by the translocation from the stems, leaves and chaff. The total amount of N in the plant decreased slightly from heading until maturity while the grain N increased. They concluded that little or no N was absorbed from soil between heading and maturity if nitrogen and phosphorus are adequate throughout the season.

According to Brengle and Greb (1963) spring applications of N should be made before the jointing stage. This agrees with N uptake presented by Boatwright and Haas (1961).

METHODS AND MATERIALS

Locations

A total of nine sites were selected for the fertilizer experiments. They are located in the Northern part of Tunisia within the wheat growing area (Figure 2).

The locations were chosen deliberately on private farms so that they serve also as fertilizer demonstrations. The soil was silt loam to silt clay loam and deep in all the locations. The rainfall varied from one location to another. The 1969-70 rainfall, the 60-year average and the previous crop for these locations are given in Table 1.

Experimental Design

The experiments were set up in a randomized block design with three replications, five levels of nitrogen, and four times of application. The plan of a typical field layout is given in Figure 3.

Fertilizer plots were 15.00 by 2.50 meters. Sixty plots were needed for each location. The total area for one experiment was 2250 m^2 with alleys. One meter border area was left between the plots.

Paper bags attached to iron rods were used to identify each plot by treatment and number for all plots and experiments. The treatments were applied as indicated in the next section. For convenience, letters will be used to designate the different treatments, i.e., "R" for rate of nitrogen, "T" for time of application.

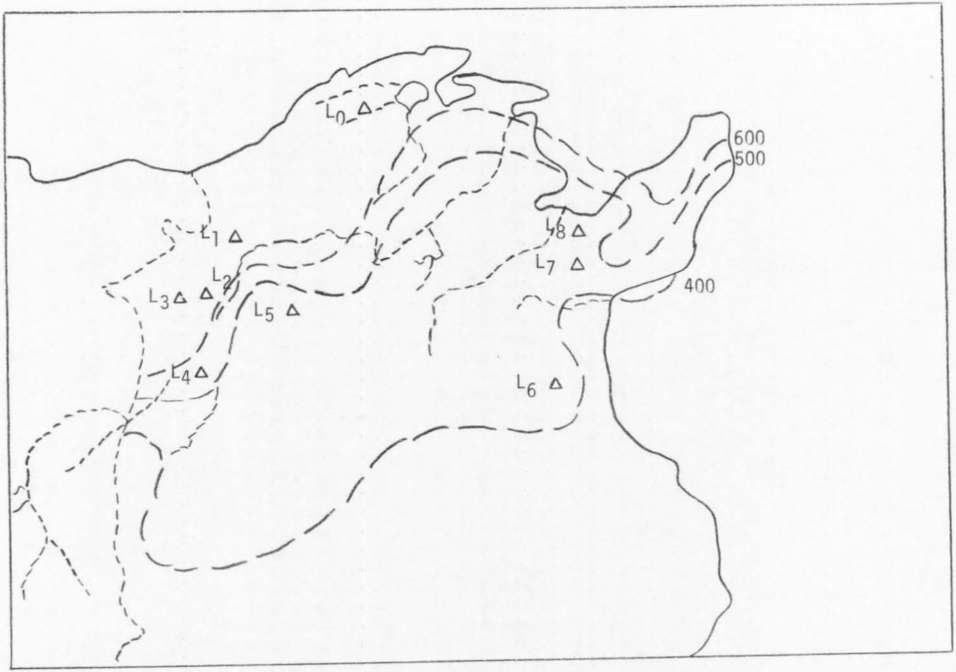

Figure 2. Distribution of the experimental sites in the North of Tunisia.

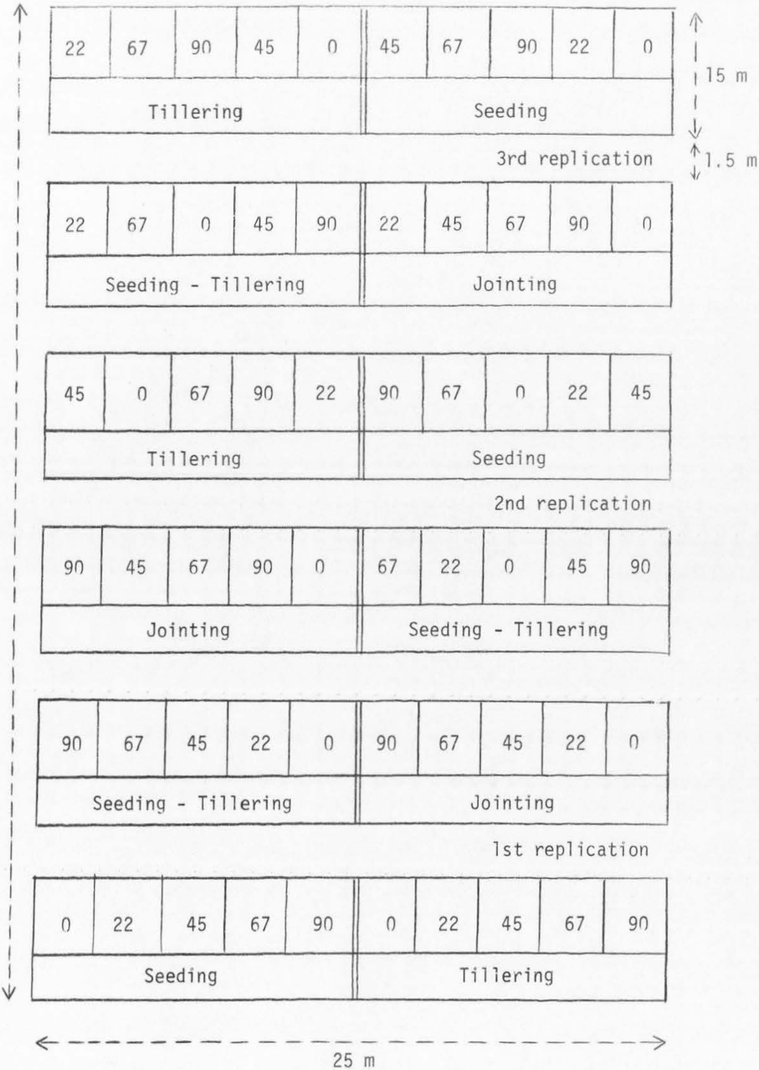

Figure 3. Typical field layout for fertilizer trial. Region of low and medium rainfall.

Table 1. Location, characteristics of experimental sites, and fertilizer treatment rates

Location	Region	Farm	Rainfall 69-70 mm	Rainfall 60-years average mm	% Rainfall for 69-70	Rate of fertilizer in Kg/ha N	Rate of fertilizer in Kg/ha P_2O_5	Previous crop	Seeding date 1969	Harvest date 1970
L_0	Mateur	Zaouch	734.9	653	112%	0, 33, 67, 90, 133	90	Garlic	12/29	6/21
L_1	Beja	Borj Hamdoun	770.5	603	123%	0, 22, 45, 67, 90	67	Legume	11/24	6/16
L_2	Bou Salem	Marja II	539.7	483	112%	0, 22, 45, 67, 90	67	Fallow	11/18	6/17
L_3	Bou Salem	Zama	539.7	483	112%	0, 22, 45, 67, 90	67	Legume	11/18	6/17
L_4	Kef	Oued Rmal	666	520	128%	0, 22, 45, 67, 90	67	Fallow	12/27	6/24
L_5	Goubellat	Jehfa	578	330	175%	0, 22, 45, 67, 90	67	Fallow	11/13	6/03
L_6	Fahs	Amel	813	384	212%	0, 22, 45, 67, 90	67	Legume	12/5	6/09
L_7	Grombalia	Bouchrik	345.2	490	70%	0, 22, 45, 67, 90	67	Fallow	12/31	6/04
L_8	Tunis	Mornag	463.1	449	103%	0, 22, 45, 67, 90	67	Fallow	12/15	6/11

Treatments

Rates of nitrogen

Two ranges of nitrogen were used, depending on the rainfall, with five rates of nitrogen in each range. The ranges and rates are shown in Table 2.

Table 2. Rates of nitrogen used in the experiments

Nitrogen treatment	Rates of nitrogen in kg/ha	
	Region of low and medium rainfall	Region of high rainfall
R_1	0	0
R_2	22	33
R_3	45	67
R_4	67	90
R_5	90	133

The source of nitrogen was ammonium nitrate (NH_4NO_3) at 33.5% of N. Phosphate was uniformly applied one month before seeding at the rate of 67 kg/ha of P_2O_5 for low rainfall region and 90 units per ha for high rainfall region. The source of phosphate was superphosphate (45% P_2O_5). Location L_0 was the only one in high rainfall region while locations L_1 through L_8 were in the low and medium rainfall regions.

Time of application

Four application times were used. They are shown in Table 3.

Table 3. Application times used in the experiments

Treatment No.	Time of application
T_1	All at seeding
T_2	All at tillering
T_3	Half at seeding, half at tillering
T_4	All at jointing

At seeding, nitrogen was broadcast using a combination grain drill and fertilizer attachment. At tillering and jointing it was broadcast by hand on the surface without incorporation into the soil.

Culture practices

Tillage

Preparation of the seedbed was done by the farmers themselves and with their equipment under the supervision of the Accelerated Cereals Production Project.

Plots were either disked or sweep-plowed after harvest and disked during the summer to control weeds. In the fall they are plowed again during the broadcasting of phosphate.

Weed control

All the experiments having broadleaf weed problems were sprayed with 2,4-D. A concentration of 600 grams of active material per ha of 2,4-D gave good weed control at most locations.

Seeding and harvesting

Seeding and harvest dates are given in Table 1 for each location. The rates of seeding were from 80 to 100 kg/ha. A strip 1.50 wide was harvested from each plot. The yield was then calculated for one hectare.

Inia 66 (Triticum aestivum, L) was the variety selected from previous variety trials.

RESULTS AND DISCUSSION

High Rainfall Area - Location L_0

The average yield results are presented in Table 4. The statistical analysis are in Table 5.

Table 4. Average yield results for location L_0 in quintals per ha

Time of application	Rates of nitrogen in kg/ha 0	33	67	90	133	Average for time
Seeding	38.6	35.5	40.2	37.6	36.8	37.7
Tillering	38.6	41.9	44.6	47.2	49.8	44.4
Seeding-tillering	40.2	40.5	39.8	41.8	40.1	40.5
Jointing	38.9	41.0	40.4	43.2	41.5	41.0
Average for rate	39.1	39.7	41.3	42.5	42.1	40.9

Time x rate	LSD 0.05 level = 3.36
	LSD 0.01 level = 4.52
Time =	LSD 0.05 level = 1.49
	LSD 0.01 level = 2.00
Rate =	LSD 0.05 level = 1.68
	LSD 0.01 level = 2.25

Table 5. Analyses of variance - mean squares for all the locations

Source of variation	df	L_0	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8
Total	59	201.37	124.97	110.56	155.32	152.16	426.01	159.83	68.91	356.73
Replications	2	38.96**	15.58	51.70**	0.44	54.01**	123.52**	66.86*	14.89	94.97*
Time	3	117.79**	19.31	32.65**	16.21	38.99**	75.68**	33.20	30.62*	95.44*
Rate	4	24.97**	67.22**	15.57**	98.73**	48.72**	216.29**	36.05	7.85	125.31**
Time & rate	12	15.75**	12.78	10.32**	30.17*	4.96	3.53	8.35	8.28	13.52
Error	38	4.17	10.07	0.30	9.77	5.48	6.99	15.37	7.27	27.49

*Significant at 0.05 level
**Significant at 0.01 level

Table 5 indicates that there was a significant effect due to nitrogen on the grain yield. It indicates also that the time of application was more effective in determining the yield than the rate of nitrogen.

The interaction between time of application and rate of nitrogen was also significant; however, it was not as effective as rate of nitrogen or time of application taken separately. The least significant difference test (Table 4) showed that the tillering stage was the optimum time for applying nitrogen. Only nitrogen applied at tillering and jointing stages had some beneficial influence but no benefit could be attributed to the very early application. This was also indicated for the split application by the fact that the split application yield increases were only as great as from the single late application.

For location L_0, 1969 was an exceptional year as far as amount of rainfall is concerned. One hundred twelve percent of the normal rainfall fell during the tillering and jointing stage. There is no doubt that a favorable distribution of moisture accounted for most of the significant effects.

The results are in agreement with those of Neiding and Snyder (1924) and Peterson (1952) and Doll (1962). Statistically, 90 kg of nitrogen applied at the tillering stage gave a much greater yield than 133 kg applied at the seeding time.

The yield increases were proportional to the amount of nitrogen applied at the tillering stage up to 90 kg. The average increase in yield from a 33 kg increment of nitrogen was 2.7 quintals.

Medium to Low Rainfall Area - L_1 to L_8

The average yield results for locations L_1 through L_8 are in Table 6. The statistical analyses are in Table 5.

The details of the grain yield results are for all the locations in the appendix, along with the table of the analysis of variance.

Yields affected by nitrogen treatment

Significant yield increases due to nitrogen were recorded at six locations out of 8 (Table 5). Generally, nitrogen up to 67 kg/ha increased yield in all locations except in locations L_6 and L_7 (Table 5). The non-effect of nitrogen on yield in Location 6 is more likely due to a high residual nitrogen in the soil accumulated from the previous crop. Rainfall history indicated that this location is usually not well watered and the nitrogen applied to the previous crop may not be used adequately. The year 1969 was a particularly wet year for L_6. The rainfall was 212% of that of the normal. The high yield in the check plots and the non-effect of time of application for L_6 confirms this explanation (Table 6).

In location L_7 the exact opposite of that of L_6 may be stated. Nitrogen had no effect on the yield and it is likely to be due to a lack of an adequate rainfall for that year. In fact L_7 received only 70 percent of normal. Most of it fell in the fall before seeding. A small effect due to the time of application was recorded in L_7 perhaps because of the relatively fair amount of rain which fell in the next two months after seeding and thus allowed the use of a part of the nitrogen applied at the seeding and tillering stages.

Table 6. Average yields for each location in quintals/ha

Treatments: Time	Rate	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8
	kg/ha								
Seeding	0	20.8	51.8	47.4	18.0	18.1	37.0	18.5	24.3
	22	28.0	48.7	45.3	21.3	22.1	43.2	21.6	32.0
	45	24.6	51.2	46.3	20.6	25.2	44.6	19.8	31.8
	67	26.2	50.9	44.1	23.7	26.7	45.7	19.5	35.4
	90	28.3	53.0	46.6	23.4	27.4	44.4	21.3	32.6
Tillering	0	19.2	50.7	35.8	21.9	16.1	42.8	20.1	24.6
	22	22.6	52.4	43.4	23.5	20.1	47.7	19.5	27.8
	45	24.3	58.5	47.1	23.8	23.7	43.9	17.9	30.3
	67	26.1	53.4	46.7	26.4	25.6	48.4	19.0	33.2
	90	30.9	54.2	48.4	25.4	28.3	46.8	18.8	34.5
Seeding - tillering	0	23.9	50.4	42.0	18.2	13.5	44.8	18.8	25.2
	22	22.3	53.0	45.3	20.6	18.2	45.5	21.8	27.7
	45	22.4	50.9	44.7	22.0	22.1	48.2	23.7	32.0
	67	26.2	50.3	52.0	22.5	25.5	46.2	22.4	33.6
	90	25.2	54.0	46.8	24.1	26.4	46.9	24.7	36.7
Jointing	0	20.0	48.1	37.3	15.7	13.6	43.8	20.9	24.9
	22	22.1	51.4	45.7	23.2	18.2	45.6	20.1	25.6
	45	23.5	51.4	41.6	21.7	19.3	45.0	22.3	25.3
	67	24.1	51.1	48.0	20.7	20.9	45.9	21.8	25.9
	90	24.3	50.2	48.4	20.9	21.6	45.5	22.5	27.5
LSD	5%	5.24	0.89	5.16	3.86	4.35	6.48	4.45	8.67
LSD	1%	7.02	1.19	6.92	5.16	5.83	8.68	5.97	11.61

For the rest of the locations, nitrogen increased the yield. All of the location received a good amount of rain in 1969, which ranged from 100 percent to 175 percent of the normal amount. The average yields in locations L_1, L_4, L_5 and L_8 were much lower than those of locations L_2 and L_3 (Table 6). Average yields obtained from the check plots of L_2 and L_3 were almost double of those obtained from the check plots L_1, L_4, L_5 and L_8. This may be accounted for by the residual nitrogen, which was probably much higher in L_2 and L_3 than in L_1, L_4, L_5 and L_8. Besides the fact that rainfall was not lacking that year, distribution probably played a big role in these differences. L_2 and L_3 (Figure 2) were in the same rainfall area; they have received the same amount of rain with the same distribution which was fairly good in these two locations. Sixty percent of the rain fell between the seeding time and the harvest. Rainfall distribution data were not available for locations L_1, L_4, L_5 and L_8.

The least significant difference test (Table 7) indicates that 45 kg of nitrogen per ha were needed to give optimum yield in one location and 90 kg were needed in two locations. In one location, there was no difference in increasing yield between the rates of 67 kg and 90 kg of nitrogen. There was also no difference between the rates of 22, 45, 67, and 90 kg of nitrogen in affecting the yield in two locations. All this variability between locations and their respectively optimum rates was due to the variability in precipitation and variability in the crop history for each location (Leggett, 1959; Jackson et al., 1952; and Army et al., 1959).

The observation of the average yields (Table 6) for each location indicates that where the soil was low in nitrogen as indicated by the yields of check plots, the heavier rates of nitrogen have given the maximum yield, while for the location where the soil had a fairly high amount of residual nitrogen, the smaller rates were required.

Table 7. Average yields as affected by rates of nitrogen in quintals/ha

Rates of nitrogen kg/ha	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8
0	20.9	50.3	40.6	18.5	15.3	42.1	19.6	24.7
22	23.8	51.4	44.9	22.2	19.7	45.5	20.8	28.3
45	23.7	53.0	44.9	22.0	22.6	45.4	20.9	29.3
67	25.7	51.4	47.8	23.3	24.7	46.6	20.7	32.0
90	27.2	52.9	47.6	23.5	25.9	45.9	21.8	32.8
LSD 5%	2.61	0.44	2.57	1.92	2.16	3.24	2.22	4.33
LSD 1%	3.50	0.59	3.44	2.57	2.90	4.34	2.98	5.80

There must be a fairly good correlation between the rain falling during the growing season, moisture in the soil before seeding, residual nitrogen and nitrogen applied (Neiding and Snyder, 1924; Leggett, 1959; Fernandez and Laird, 1959; and Hallstead and Mathew, 1936)

In all the locations the first 22 kg increment of nitrogen, regardless of the time of application, gave the highest increase in yield ranging from 1.1 to 4.4 quintals/ha with an average of 1.5 quintals/ha (Table 7). The average yields for each location indicate that the optimum rate was 67 kg/ha which gave an increase in yield ranging from 1.19 to 9.4 quintals/ha with an average of 5.4 quintals/ha.

Effect of the time of application on the yield

The effect on yield of the time of application of nitrogen was significant at the 1 percent level only in three locations. At the 5 percent level it was significant in two locations while in the other three locations, it was not significant (Table 5).

This variability in the effect of time of application was expected since it follows closely the pattern and variability in the rainfall (Leggett, 1959; and Peterson, 1952). The rainfall varies from a maximum of 770 mm to a minimum of 345 mm for the growth year.

In all the locations, the early application (seeding, tillering, and seeding-tillering) had a beneficial effect. Little or no benefit could be attributed to the late application (jointing) as indicated by the fact that the split application yield increases were only as great as from the early application (Table 8). It is likely that there is not enough rainfall to carry nitrogen to the root zone after the jointing application. It was thought that the early application with an optimum moisture content in the soil would increase yields while the late application with low moisture content in the soil would increase the protein content and thus the quality of the wheat (Neiding and Snyder, 1924; and Peterson, 1952). Nitrogen uptake by the plant decreases slightly from heading until maturity while the grain nitrogen, thus the protein content, increases (Boatwright and Viets, 1961; and Brengle and Greb, 1963). No protein data on the wheat has been made available yet.

The average yields for each location indicate that the early applications (seeding, tillering, seeding-tillering) are the optimum times with a slight advantage for the seeding and the seeding-tillering applications. Each application has some advantages. In the fall and at the seeding time, the land is usually easy to get on and the nitrogen can be applied anytime. During the tillering stage, the soil and climate conditions may not be favorable. The fertilizer must be broadcast when the foliage is dry so that the fertilizer will not adhere to the plant and cause burning (Peterson, 1952).

Table 8. Average yields as affected by time of application in quintals/ha

Time of application	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8
Seeding	25.5	51.1	45.9	21.4	23.9	43.0	20.1	31.2
Tillering	24.6	53.8	44.3	24.2	22.8	45.9	19.1	30.1
Seeding-tillering	24.0	51.7	56.2	21.5	21.1	46.3	22.3	31.0
Jointing	22.8	50.4	44.2	20.4	18.7	45.2	21.5	25.8
LSD 5%	2.37	0.40	2.30	1.72	1.94	2.87	1.96	3.86
LSD 1%	3.17	0.54	3.09	2.30	2.60	3.85	2.63	5.18

Split application (seeding-tillering) seems to have both the advantage of early application and the disadvantage of the tillering application, but it has an overall advantage in that it offers the grower, besides applying N at seeding time (Ramig and Rhoades, 1963; Hallstead and Mathew, 1936), an opportunity to evaluate the soil moisture conditions. This evaluation offers him an opportunity to adjust the rate. In other words, more flexibility is offered him in managing his crop.

Interaction time of application x nitrogen applied

The interaction effect was only significant in 2 locations, one at the 1 percent level, the second at the 5 percent level. These two locations are L_2 and L_3 and are in the same area and had the same amount and distribution of rainfall. The least significant difference (Table 6) for these two locations showed that 67 kg of N/ha applied rather early gave the optimum yield.

Although the interaction is not statistically significant in all the locations, the average yields (Table 6) indicate that in all the locations 67 kg of nitrogen per ha applied early during the growth stages gave the optimum yield. In no location the late application (jointing) gave the optimum yield.

Method of Application

Some studies have shown that the method of application of the fertilizer may be more important than the time of application. Laboratory work showed that nitrogen can be lost in the form of gaseous ammonia when the fertilizer was applied on the soil. The degree of loss depends on the nitrogen carrier and the tillage practices after the application of the fertilizer.

Nelson et al. (1966) found that cultipacking the soil after applying the fertilizers resulted in higher wheat yields than deep disking and cultipacking, or deep spring-tooth harrowing and cultipacking the soil. They explained this by the fact that the nitrogen carriers were brought into the soil surface layer by the latter two tillage methods. Nelson et al. (1966) found also that ammonium nitrate and calcium nitrate when topdressed in the fall and spring yielded more than when shanked in the fall. An interaction with methods of application and N rates of ammonium sulfate occurred. Topdressed ammonium sulfate in the spring was less effective than shanking the material at lower rates of N application. They were working on rill-irrigated Gaines wheat.

Combined Analysis of Variance for Grouped Locations

All the experiments in all the locations were identical in structure. This type of experimentation is usually undertaken in the hope that the results can be applied in practical farming. These results, if they are to be used, must be valid for at least several seasons in the future and over a reasonably large area (Cochran and Cox, 1968).

In experiments designed to lead to the best management practices, we wish to know whether there is a consistent superiority of certain treatments for different circumstances. To achieve this, a combined analysis of variance can be computed. The test would indicate whether the responses to treatment have varied with the external conditions of the experiment. However, this type of analysis is open to question and criticism. A main criticism concerns the assumption that the experimental error variances are the same in all experiments. Such assumption is seldom attainable in experiments dealing with crops because the natural variability among pieces of land at one place differs from that at other places. Despite this, some conclusions can be drawn as far as possible from this analysis (Cochran and Cox, 1968).

In the experiments conducted here, a combined analysis was attempted to two groups of locations. The grouping was based on the rainfall of the 1969-70 year. One group consisted of the locations which received more than 50 mm of rainfall and the second consisted of those which received less than 500 mm. The distribution of locations was as follows:

More than 500 mm	Less than 500 mm
L_1	L_7
L_2	L_8
L_3	
L_4	
L_5	
L_6	

The combined analysis of variance for the two groups are shown in Tables 9 and 10. It is important to notice that the experimental error has a certain heterogeneity as well as the interactions variances among the locations (Table 5). The error varied from a value of 0.30 (L_2) to a value of 27.09 (L_8). The results showed a sizeable value for locations and the interaction of location x time x rate for both groups.

Table 9 indicates a substantial difference among treatment and locations, yet interactions are negligible except only for the three-way interaction of location x rate x time. This interaction is usually difficult to interpret though it indicates that some other factors are involved besides the rate and time in affecting the yields.

In Table 10, the F-ratio for the treatments and interactions are highly significant, the big ratio for the three-way interaction is, again, difficult to interpret, however it indicates that there are some external factors (rainfall amount and distribution, soil type, etc.) which affected the yield other than the treatments rate and time.

Table 9. Combined analysis of variance for locations receiving more than 500 mm of rain = L_1, L_2, L_3, L_4, L_5 and L_6

Source of variances	Degree of freedom	Sum of squares	Mean sum of squares	"F" value
Total	289	2,215,770.74	48,164.39	
Locations	5	57,021.89	11,404.37	927.93**
Replications	2	624.25	312.12	25.39
Time	3	307.14	102.38	8.33**
Rate	4	1,553.14	388.28	31.59**
Rate x time	12	180.44	15.03	1.22
Location x time	15	341.06	22.73	1.84
Location x rate	20	377.29	18,86	1.53
Location x rate x time	60	2,153,300.36	35,888.33	2,920.12**
Error	168	2,065.17	12.29	

**Significant at the 0.01 level.

Table 10. Combined analysis of variance for locations with less than 500 mm of rain = L_7 and L_8

Source of	Degree of freedom	Sum of squares	Mean sum of squares	"F" value
Total	113	78,100.02	9,048.31	
Locations	1	2,542,89	2,542.89	195.00**
Replications	2	219.72	109.86	8.42
Time	3	183.64	61.21	4.69**
Rate	4	349.95	87.48	6.70**
Time x rate	13	128.82	10.13	0.82
Location x time	3	194.57	64.85	4.97**
Location x rate	4	182.71	45.67	3.50**
Location x rate x time	12	73,358.21	6,113.18	468.80**
Error	72	939.51	13.04	

**Significant at the 0.01 level.

SUMMARY AND CONCLUSIONS

A nitrogen trial on Mexican wheat variety, Inia 66, was conducted in 9 different locations. Two ranges of nitrogen rate were used. 0, 33, 67, 90 and 133 kg per ha was the range used for high rainfall area and 0, 22, 45, 67 and 90 was the second range used for the medium to low rainfall area.

N was found to increase the Mexican wheat yield. The optimum rate and time of application depend on the rainfall.

In the medium to low rainfall area, early applications (seeding, tillering) were more effective on the yield increase than the later ones; 67 kg of N per ha applied early gave the optimum yield.

In the high rainfall area, early N applications had no effect on yield while late applications increased yield, 90 kg of N per ha applied at the tillering and later gave the optimum yield.

Split application could be more easily accepted by the Tunisian farmer since it gives him more flexibility in deciding whether or not he has to apply the second application by evaluating his soil moisture content and, therefore, gives him a stronger security feeling in that he is not risking his money by applying nitrogen which will not have any effect on his production.

By using the variety, Inia 66, yield was significantly increased, yields obtained were 55 percent higher than the yield of the local standard variety (Florence-Aurore). In order to reach the goal set for the Tunisian wheat production, that is, to become self-sufficient in soft wheat production, more land should be seeded with these high yielding varieties under good crop management.

Implications for further research

The results of this work indicate that the wheat yield is influenced not only by the rate and time of N application, but also by some other factors, e.g., residual N, moisture in the soil and amount and distribution of the rain during the growth season. These factors complement each other in determining the yield, and they are related to each other by a close relationship. Some more research work should be done under dryland and irrigated conditions in order to determine a formula for this relationship. Such kind of formula will allow us to predict the yield by knowing the variables affecting it, thus allow us a better management of the crop in order to obtain a good production in the optimum economical conditions. The big lines for future research might be:

1. Determine the relation between yield and available moisture in the soil.
2. Determine the relation between the yield and available nitrogen for the crop.
3. Determine which varieties are the most adapted to Tunisian climatic conditions under irrigation.
4. Study the nutrient requirements of the varieties under irrigated conditions.

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APPENDIX

Table 11. Grain yields in quintals/ha for location L_0

Time of application	Repli-cation	Rates of nitrogen in kg/ha 0	33	67	90	133
Seeding	1	40.0	36.4	37.7	38.2	36.0
	2	37.3	36.0	47.1	40.4	40.0
	3	38.6	34.2	36.0	34.2	34.6
Tillering	1	38.6	40.4	44.4	44.8	50.2
	2	42.6	42.2	44.8	48.0	50.6
	3	34.6	43.1	44.8	48.8	48.8
Seeding-tillering	1	39.5	39.1	40.0	44.0	39.5
	2	41.7	41.3	39.5	40.8	40.4
	3	39.5	41.3	40.0	40.8	40.4
Jointing	1	41.3	38.2	42.2	44.4	41.3
	2	40.0	43.5	40.8	43.1	44.8
	3	35.5	41.3	38.2	42.2	38.6

Table 11a. Analysis of variance for location L_0

Sources of variance	Degrees of freedom	Sum of squares	Mean sum of squares	"P" value
Total	59			
Replications	2	77.92	38.96	9.3**
Time	3	353.37	117.79	28.24**
Rate	4	119.90	24.97	5.98**
Time x rate	12	189.05	15.75	3.77**
Error	38	158.77	4.17	

*Significant at 0.05 level.
**Significant at 0.01 level.

Table 12. Grain yields in quintals/ha for location L_1

Time of application	Repli-cation	Rates of nitrogen in kg/ha				
		0	22	45	67	90
Seeding	1	15.5	28.4	24.0	26.6	28.9
	2	26.2	28.9	28.4	28.9	27.5
	3	19.5	26.6	21.3	23.1	28.4
Tillering	1	20.9	22.6	25.8	28.0	33.7
	2	18.6	23.1	24.4	25.8	32.0
	3	18.2	22.2	22.6	24.4	27.1
Seeding-tillering	1	20.0	20.4	21.8	24.4	20.0
	2	25.8	23.5	23.1	29.3	33.3
	3	25.8	23.1	22.2	24.9	22.2
Jointing	1	23.1	26.6	26.6	26.6	20.0
	2	17.3	17.8	21.8	23.1	23.5
	3	19.5	21.8	22.2	22.6	29.3

Table 12a. Analysis of variance for location L_1

Sources of variance	Degrees of freedom	Sum of squares	Mean sum of squares	"P" value
Total	59	849.18		
Replication	2	31.17	15.58	1.54
Time	3	57.93	19.31	1.91
Rate	4	268.90	67.22	6.67**
Time x rate	12	153.36	12.78	1.26
Error	38	382.82	10.07	

*Significant at 0.05 level.
**Significant at 0.01 level.

Table 13. Grain yields in quintals/ha for location L_2

Time of application	Replication	Rates of nitrogen in kg/ha				
		0	22	45	67	90
Seeding	1	54.2	52.4	52.8	48.8	53.7
	2	56.8	50.2	53.3	54.6	52.4
	3	44.4	43.5	47.5	49.3	52.8
Tillering	1	52.8	57.3	62.6	54.6	55.1
	2	51.9	48.0	61.3	52.4	57.3
	3	47.5	51.9	51.5	53.3	50.2
Seeding-tillering	1	47.1	45.3	49.7	51.1	56.4
	2	55.4	55.9	51.1	51.1	52.4
	3	48.8	57.7	51.9	48.8	53.3
Jointing	1	45.7	51.1	55.5	54.2	53.7
	2	50.2	55.1	48.4	47.5	44.0
	3	48.4	48.0	50.2	51.5	48.0

Table 13a. Analysis of variance for location L_2

Sources of variance	Degrees of freedom	Sum of squares	Mean sum of squares	"P" value
Total	59	399.21		
Replications	2	103.41	51.70	172.23**
Time	3	97.96	32.65	108.83**
Rate	4	62.30	15.57	51.91**
Time x rate	12	123.87	10.32	86.00**
Error	38	11.67	0.32	

*Significant at 0.05 level.
**Significant at 0.01 level.

Table 14. Grain yields in quintals/ha for location L_3

Time of application	Repli-cation	Rates of nitrogen in kg/ha				
		0	22	45	67	90
Seeding	1	48.8	51.9	48.8	48.0	47.5
	2	47.1	44.0	41.7	41.3	44.0
	3	40.0	40.0	48.4	43.1	48.4
Tillering	1	40.0	37.3	48.4	42.6	42.6
	2	36.4	43.5	49.7	47.5	49.3
	3	31.1	49.3	43.1	50.6	53.3
Seeding-tillering	1	37.7	49.7	45.3	51.5	53.7
	2	41.3	39.1	43.5	51.1	41.3
	3	47.1	47.1	45.3	53.3	45.3
Jointing	1	28.9	44.4	40.4	44.4	49.7
	2	40.0	48.0	51.9	50.2	50.2
	3	43.1	44.8	32.4	49.3	45.3

Table 14a. Analysis of variance for location L_3

Sources of variance	Degrees of freedom	Sum of squares	Mean sum of squares	"P" value
Total	59			
Replications	2	0.89	0.44	0.04
Time	3	48.65	16.21	1.65
Rate	4	394.93	98.73	10.10**
Time x rate	12	362.12	30.17	3.08*
Error	38	341.33	9.77	

*Significant at 0.05 level.
**Significant at 0.01 level.

Table 15. Grain yields in quintals/ ha for location L_4

Time of application	Repli-cation	Rates of nitrogen in kg/ha				
		0	22	45	67	90
Seeding	1	17.3	20.9	20.0	22.2	22.2
	2	18.2	22.6	17.8	22.2	23.5
	3	18.6	20.4	24.0	26.6	24.4
Tillering	1	17.3	18.2	22.2	24.0	22.2
	2	22.2	20.4	24.0	25.8	24.2
	3	26.2	32.0	25.3	29.3	29.7
Seeding-tillering	1	17.8	20.0	22.6	22.6	24.9
	2	16.0	17.8	20.0	20.9	23.1
	3	20.9	24.0	23.5	24.0	24.4
Jointing	1	13.8	20.4	20.4	20.4	21.8
	2	17.8	25.8	22.6	22.6	20.0
	3	15.5	23.5	22.2	19.1	20.9

Table 15a. Analysis of variance for location L_4

Sources of variance	Degrees of freedom	Sum of squares	Mean sum of squares	"P" value
Total	59	687.95		
Replications	2	108.02	54.01	9.85**
Time	3	116.98	38.99	7.11**
Rate	4	194.88	48.72	8.89**
Time x rate	12	59.63	4.96	0.90
Error	38	208.44	5.48	

*Significant at 0.05 level.
**Significant at 0.01 level.

Table 16. Grain yields in quintals/ha for location L_5

Time of application	Repli- cation	Rates of nitrogen in kg/ha 0	22	45	67	90
Seeding	1	20.9	20.4	23.1	24.0	26.6
	2	12.0	20.0	23.5	24.0	25.3
	3	21.3	25.8	28.9	32.0	30.2
Tillering	1	13.3	20.0	20.0	24.0	28.0
	2	13.3	17.8	24.9	25.3	28.0
	3	21.8	22.6	26.2	27.1	28.9
Seeding-tillering	1	16.4	19.5	24.9	26.2	30.2
	2	9.3	14.7	17.3	24.9	23.1
	3	14.7	20.4	24.0	25.3	25.8
Jointing	1	11.5	17.8	20.0	24.0	24.0
	2	9.3	17.3	16.9	16.4	15.5
	3	20.0	19.5	20.9	22.2	25.3

Table 16a. Analysis of variance for location L_5

Sources of variance	Degrees of freedom	Sum of squares	Mean sum of squares	"P" value
Total	59	1647.43		
Replications	2	247.05	123.52	17.67**
Time	3	227.06	75.68	10.82**
Rate	4	865.19	216.29	30.94**
Time x rate	12	42.39	3.53	0.50
Error	38			

*Significant at 0.05 level.
**Significant at 0.01 level.

Table 17. Grain yields in quintals/ha for location L_6

Time of application	Repli-cation	Rates of nitrogen in kg/ha				
		0	22	45	67	90
Seeding	1	31.5	40.0	41.3	44.0	43.1
	2	44.0	48.8	48.4	49.7	51.1
	3	35.5	40.8	44.0	43.5	39.1
Tillering	1	42.6	44.4	41.3	47.5	48.8
	2	44.4	48.0	45.7	45.3	46.2
	3	41.3	50.6	44.8	52.4	45.3
Seeding-tillering	1	45.7	43.1	45.7	42.2	40.0
	2	44.4	46.2	48.8	47.1	50.6
	3	44.4	47.1	50.2	49.3	50.2
Jointing	1	48.8	48.8	45.3	51.1	48.0
	2	45.7	45.3	45.7	50.2	48.4
	3	36.9	42.6	44.0	36.4	40.0

Table 17a. Analysis of variance for location L_6

Sources of variance	Degrees of freedom	Sum of squares	Mean sum of squares	"P" value
Total	59	1062.06		
Replications	2	133.72	66.86	4.35*
Time	3	99.60	33.20	2.16
Rate	4	144.22	36.05	2.34
Time x rate	12	100.27	8.35	0.57
Error	38	584.25	15.37	

*Significant at 0.05 level.
**Significant at 0.01 level.

Table 18. Grain yields in quintals/ha for location L_7

Time of application	Replication	Rates of nitrogen in kg/ha				
		0	22	45	67	90
Seeding	1	18.6	20.0	19.5	18.2	19.1
	2	16.4	23.5	24.0	20.9	23.1
	3	20.4	21.3	16.0	19.5	21.8
Tillering	1	20.0	17.3	20.4	17.8	19.5
	2	19.1	25.3	15.5	21.8	20.4
	3	21.3	16.0	17.8	17.3	16.4
Seeding-tillering	1	22.2	23.1	24.0	27.5	26.2
	2	20.9	22.2	24.0	17.8	25.8
	3	13.3	20.0	23.1	21.8	22.2
Jointing	1	22.2	20.9	22.2	17.8	24.9
	2	16.9	20.0	24.4	26.2	20.0
	3	23.5	19.5	20.4	21.3	22.6

Table 18a. Analysis of variance for location L_7

Sources of variance	Degrees of freedom	Sum of squares	Mean sum of squares	"P" value
Total	59	528.91		
Replications	2	29.78	14.89	2.04
Time	3	91.88	30.62	4.21*
Rate	4	31.42	7.85	1.07
Time x rate	12	99.39	8.28	1.13
Error	38	276.44	7.27	

*Significant at 0.05 level.
**Significant at 0.01 level.

Table 19. Grain yields in quintals/ha for location L_8

Time of application	Repli-cation	Rates of nitrogen in kg/ha 0	22	45	67	90
Seeding	1	30.6	35.1	32.9	36.4	35.1
	2	21.3	32.4	36.0	40.0	30.6
	3	20.9	28.4	26.6	29.7	32.0
Tillering	1	23.5	22.2	31.5	36.0	40.8
	2	26.2	28.9	33.3	36.0	33.7
	3	24.0	32.4	26.2	27.5	28.9
Seeding-tillering	1	26.2	28.9	34.2	35.5	40.4
	2	27.5	23.5	34.2	33.3	36.9
	3	21.8	30.6	27.5	32.0	32.9
Jointing	1	25.8	25.8	23.0	22.6	30.6
	2	28.4	31.5	26.6	27.5	26.6
	3	20.4	19.5	26.2	27.5	25.3

Table 19a. Analysis of variance for location L_8

Sources of variance	Degrees of freedom	Sum of squares	Mean sum of squares	"P" value
Total	59	2184.57		
Replications	2	189.94	94.97	3.45*
Time	3	286.32	95.44	3.47*
Rate	4	501.24	125.31	4.55**
Time x rate	12	162.30	13.52	0.49
Error	38	1044.77	27.49	

*Significant at 0.05 level.
**Significant at 0.01 level.

VITA

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