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Effect of foliar urea spraying and nitrogen application at sowing upon dry matter and nitrogen distribution in wheat *(Triticum aestivum* L)

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Summary — The effects of foliar urea spraying at field level at 3 different developmental wheat stages upon grain yield, its components, and N accumulation and distribution within the plant were studied on Buck Pucará, a cultivar with Mexican germplasm and high grain yielding potential. Plants were grown at 2 N levels: no N and 100 kg N ha applied at sowing as granular urea, without (control) and with foliar urea spraying (20 kg N/ha) at the end of tillering (T_1), at anthesis (T_2), or 14 days after anthesis (T_3). Spraying at T_1 increased ear number/m^2, biological yield, grain yield, harvest index, total N uptake and nitrogen harvest index. It also increased grain set, without affecting fertile spikelet/spike. Spraying at T_2 or afterwards, increased grain %N and plant %N at maturity but did not improve N allocation in the grain, grain yield and its components. Spraying at T_1 only increased grain %N, total %N and %N of the vegetative organs when N availability at sowing was high.

nitrogen / urea / wheat / yield / foliar spraying / biomass

Résumé — Effet de l'application d'une fumure azotée au semis et d'une pulvérisation foliaire d'urée sur la répartition de matière sèche et de l'azote dans le blé *(Triticum aestivum* L). *On étudie, sur des parcelles de blé ayant ou non reçu de l'engrais azoté au semis (100 kg/ha), l'effet d'une application foliaire d'urée sur le rendement en grain, ses composantes et la répartition de l'azote entre organes. L'essai est réalisé au champ à La Plata (Argentine) avec le cultivar Buck Pucará, caractérisé par un potentiel de production élevé. Pour chaque modalité de fertilisation au semis, 4 traitements différents, qui concernent la fertilisation foliaire, sont mis en place: C = témoin sans fertilisation ;* T_1 *= 20 kg N/ha à la fin du tallage ;* T_2 *= 20 kg N/ha à l'anthèse ;* T_3 *= 20 kg N/ha 14 jours après l'anthèse. L'application de l'azote au semis modifie la production de matière sèche et sa répartition à maturité : le rendement en grain est augmenté avec un indice de récolte plus faible (tableau I). La pulvérisation foliaire d'urée au tallage augmente le nombre d'épis /m*^{2}*, le nombre de grains/épillet, la biomasse, le rendement en grains et l'indice de récolte (HI) (tableaux I et II). Mais le nombre d'épillets fertiles par épi et le poids d'un grain restent inchangés. La quantité d'azote absorbé et l'indice de récolte pour l'azote (NHI =* $N_{grain} / N_{total\ parties\ aériennes}$*) sont accrus (tableau III). Les teneurs en azote du grain et des pailles ne sont augmentées que sur le traitement fertilisé au semis (tableau IV). Les pulvérisations à l'anthèse et après celle-ci augmentent la teneur en azote du grain et de la plante entière à maturité mais n'affectent ni le rendement, ni ses composantes, ni les indices de récolte (HI et NHI) (tableaux I, II et IV).*

foliaire / biomasse / urée / blé / rendement / pulvérisation

INTRODUCTION

Nitrogen availability during crop growth is a determining factor for grain yield and grain protein percentage in wheat. Nitrogen fertilization at sowing commonly increases grain yield as a result of increases in ear number/m^2. However, this increase in ear number/m^2 is widely associated with a decrease in harvest index (Darwinkel, 1979; Donald, Hamblin, 1976). Furthermore, not all the tillers produced by N fertilization at sowing bear ears at maturity. To minimize this, N applications can be delayed until the time of tillering. (Coic, 1960; Scott *et al*, 1977).

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It is well known that early nitrogen supply generally increases yield and decreases grain protein percentage, especially when N supply is low (Fernandez, Laird, 1959). This is in agreement with the inverse relationship between yield and grain protein percentage (Kramer, 1979; Mesdag, 1979; Terman, 1979; Loffler *et al*, 1985).

Scholz (1984) claimed out that protein production could be improved by increasing plant N absorption or N translocation from the vegetative structures towards the grain. A low genetical variation has been found in wheat for plant N uptake (Johnson *et al*, 1968; Dubois, Fossati, 1981; Sarandón, Chidichimo, 1985), then the most effective way to obtain high grain protein yield might be to increase N allocation in the grain.

High N availability increased N content and percentage in the plant whereas it diminished N distribution to the grain (Neales *et al*, 1963; Andersen, Koie, 1975; Halloran, 1981). However, late N applications during crop growth, for example urea spraying, effectively increases grain protein percentage (Finney *et al*, 1957; Sarandón *et al*, 1986). Nevertheless, the origins of this positive increment in grain protein content remain unknown.

The aim of this work was to study the effects of N fertilization at sowing and foliar urea spraying at 3 developmental stages upon grain yield and its components, N accumulation and distribution and their relationship with grain %N in a wheat cultivar of high yielding potential.

MATERIALS AND METHODS

The assay was carried out in the field at the Gorina Experimental Station, La Plata (SL 34 54'), Ecological Subregion II South, in a clay loamy soil. Weather conditions in the trial location are characterized by a mild climate without dry season and mean temperatures of 9 °C during winter and 22 °C during summer. Annual rainfall is around 970 mm. Weather conditions during crop growth are shown in fig 1.

Buck Pucará -BP- (*Triticum aestivum* L) a cultivar with Mexican germplasm and high yielding potential was used. Sowing was carried out on July 11 at a density of 250 plants/m^2, in a randomized block design with 4 replications (each plot 7.70 m^2; 5.50 x 1.20 m). Soil analysis at sowing showed: carbon: 2.92%; total N: 0.26%; N-nitrates: 23 mg/kg; available phosphorus: 7.0 mg/kg and carbon/nitrogen: 11.

From these data 100 kg/ha of NPK (0-46-0) were applied. At that moment, granular urea, 100 kg N/ha (46-0-0) was also applied to half the plots (NS), while the other half remained without N (NNS). In addition, a 12% commercial urea solution plus a wetting agent was sprayed at 20 kg N/ha at the end of tillering (T_1), anthesis (T_2) and 2 weeks after anthesis (T_3). Control plots were not subjected to spraying.

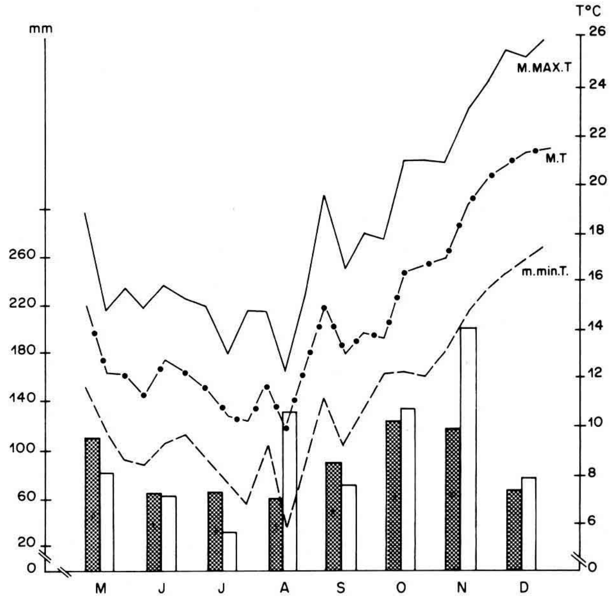

Fig 1. Monthly rainfall and weekly temperatures during crop development in 1986. M.Max *T* = mean maximum temperature; *MT* = mean temperature; m.min.*T* = mean minimum temperature. White bars represent the mean of rainfall during 1986. Grey bars represent the mean rainfall for several years.

Urea spraying at tillering (September 29) coincided with stages 22-25 of Tottman *et al* (1979) in NNS plots and with stage 31 in NS. At that moment the apex was at the terminal spikelet stage. Anthesis (3 October) coincided with stage 69.

At maturity (12 December) 3 rows (each fraction 0.50 m long) per plot were harvested. Plants were cut at ground level, separated into leaves, stems, chaff and grain (harvest index -HI-) and dried at 70 °C during 48 h. The biological yield was considered as the total aerial dry matter production.

The material was ground in a Cyclone Sample Mill (UDY), for humidity determination. Nitrogen percentage of each plant fraction was determined by the Micro Kjeldahl method (43-13, AACC, 1983). Nitrogen harvest index (NHI) was calculated as grain N/total plant N (grain + straw + chaff). The ratio NHI/HI was analyzed to evaluate the influences of fertilization upon the relative efficiency of dry matter and nitrogen distribution.

An analysis of variance was performed and differences determined by Tukey test ($P \leq 0.05$).

RESULTS

Effect upon dry matter accumulation and distribution, grain yield and its components

Nitrogen application at sowing (NS) modified dry matter production and partitioning at maturity (table I), increasing grain yield 43% and biological yield 65%, which resulted in a low harvest index. The number of fertile spikelets per spike was increased, but a decrease in grain number per spikelet led to no significant difference in grain number per spike (table II).

N application at sowing increased grain number per m^2 which was the most important factor in relation to grain yield ($r = 0.992^{**}$). It depended more on ears per m^2 ($r = 0.900^{**}$) than on grain number per spike ($r = 0.392^{*}$), which was not significantly modified.

Urea spraying at tillering (T_1) increased ear number per m^2, biological yield (30%), grain yield (48%) and harvest index. Fertile spikelet number per spike was not modified by N spraying, though in T_1 grain set was improved, thus grain number per spikelet, grain number per spike and ear weight were higher in this treatment. The increase in grain number per m^2 resulted from an

Table I. Effect of foliar nitrogen fertilization upon grain yield and dry matter distribution.

(1) Least significant differences between treatments within each fertility condition. (2) Least significant differences between fertility conditions. ns = no significative.

Treatments	*kg/ha biol yield*	*kg/ha grain yield*	*dry matter distribution (%)*			
			Leaf	*Stem*	*Chaff*	*Grain (HI)*
No N at sowing						
Control	7760	3200	15.7	33.3	10.0	41.1
T_1	11330	5166	13.6	30.5	10.4	45.5
T_2	8640	3570	15.7	32.9	10.0	41.4
T_3	7790	3230	15.7	31.8	11.0	41.5
Average	8881	3791	15.2	32.1	10.3	42.2
N at sowing						
Control	13820	4810	18.5	38.5	8.2	34.8
T_1	16570	6650	17.0	34.0	9.0	40.1
T_2	14260	5190	17.6	37.5	8.5	36.4
T_3	14040	5020	16.4	37.2	10.7	35.8
Average	14673	5415	17.4	36.8	9.1	36.8
LSD (1)	2515	1174	2.6	3.3	5.4	4.4
LSD (2)	936	437	0.97	1.2	2.0	1.6
Interaction	ns	ns	ns	ns	ns	ns

Table II. Effect of foliar nitrogen fertilization upon several yield components.

(1) Least significant differences between treatments within each fertility condition. (2) Least significant differences between fertility conditions (ns and nns).

Treatments	*Ear/m^2*	*Fertile spikelet number/spike*	*Grain number/ spikelet*	*Grain number/ spike*	*Kernel weight (mg)*	*Weight per spike*	*Grain number/ m^2*
No N sowing							
Control	324	14.1	2.0	27.9	35.2	1.22	9096
T_1	468	14.0	2.1	29.9	36.9	1.35	13995
T_2	370	14.1	1.9	27.1	35.5	1.20	10062
T_3	343	14.1	1.9	27.3	34.5	1.19	9352
Average	376	14.1	2.0	28.0	35.5	1.24	10626
N at sowing							
Control	544	14.6	1.7	24.5	36.3	1.10	13239
T_1	581	15.7	2.0	30.6	35.9	1.40	18513
T_2	532	15.2	1.7	24.1	37.4	1.29	13877
T_3	530	15.0	1.8	26.7	35.5	1.23	14135
Average	547	15.1	1.8	27.0	36.2	1.25	14941
LSD (1)	101	1.16	0.14	3.40	1.70	0.13	3146
LSD (2)	37.4	0.43	0.05	1.26	0.63	0.05	1170
Interaction	ns	ns	ns	ns	*	*	ns

* $P \leq 0.05$;
** $P \leq 0.01$

increase of ears per m^2 and of grain number per spike (table II).

Nitrogen application at sowing and spraying at tillering only modified parameters related with grain number per m^2, but not in kernel weight. Treatments at anthesis (T_2) and post-anthesis (T_3) neither affected grain yield nor its components (tables I and II).

Effect upon nitrogen accumulation and redistribution

At maturity, total N uptake ranged between 74 and 146 kg/ha and was higher for the plots receiving N at sowing (table III). Urea spraying also increased it, but treatments at anthesis and post-anthesis had less effect. Nitrogen application at sowing reduced nitrogen distribution efficiency to the grain (NHI), but improved the relationship NHI/HI.

Nitrogen application at sowing also diminished grain %N and total %N in the plant (table IV). All N spraying treatments, excluding that performed at tillering (T_1) on plots without N at sowing, increased total plant %N, which was inversely related ($r = -0.736^*$) to the biological yield. Spraying at tillering (T_1) decreased grain %N in plots that had no N at sowing. Later sprayings (T_2 and T_3) increased grain N%, independently of N treatment at sowing (table IV).

DISCUSSION

Grain yield was increased by sowing fertilization due to a greater number of ears per m^2, confirming that early N availability promotes tiller formation (Langer, 1966). When water is not a limiting factor, as in this experiment, early N applications induce greater vegetative growth and a higher N consumption by tillers that, sometimes do not form heads, but exerts competition for resources at some developmental stages. The importance of this competition depends on when it takes place and on the yield component affected at that time. In this assay, competition was operating upon grain set, decreasing grain number per spikelet and ear weight. This resulted in a decrease in harvest index, which is consistent with a less efficient dry matter distribution at high densities (Donald, Hamblin, 1976; Darwinkel, 1979). The increase in grain number per spikelet, as observed when N was sprayed at anthesis, shows that nitrogen can act as a limiting factor, even when the crop is fertilized at sowing.

When N was applied at tillering, head population increased, showing that nitrogen

Table III. Effect of foliar N fertilization upon N distribution at maturity.
(1) Least significant differences between treatments within each fertility conditions. (2) Least significant differences between fertility conditions (ns and nns).

Treatments	*Total N uptake kg/ha*	*Nitrogen distribution (%)*			
		grain (NHI)	*Leaf*	*Stem*	*NHI/HI*
No N at sowing					
Control	74	81.2	7.5	6.7	1.98
T_1	109	85.7	5.3	5.1	1.86
T_2	92	80.1	8.0	7.4	1.94
T_3	81	80.1	7.6	7.3	1.93
Average	89	81.8	7.1	6.6	1.93
N at sowing					
Control	105	75.8	9.9	10.5	2.18
T_1	146	79.6	7.7	8.0	2.00
T_2	130	77.8	8.9	9.0	2.15
T_3	122	76.4	9.0	8.9	2.14
Average	126	77.4	8.9	8.9	2.12
LSD (1)	24.6	3.59	1.45	1.08	0.14
LSD (2)	9.2	1.34	0.54	0.41	0.05
Interaction	ns	ns	ns	**	ns

Table IV. Effect of foliar N fertilization upon N content of plant parts at maturity (% of dry matter).
(1) Least significant differences between treatments within each fertility conditions. (2) Least significant differences between fertility conditions.

Treatments	*Total*	*Leaf*	*Stem*	*Grain*	*Chaff*
No N at sowing					
Control	0.95	0.46	0.19	1.88	0.43
T_1	0.96	0.38	0.16	1.85	0.35
T_2	1.06	0.54	0.24	2.06	0.48
T_3	1.05	0.51	0.24	2.03	0.48
Average	1.00	0.47	0.21	1.95	0.43
N at sowing					
Control	0.76	0.40	0.21	1.65	0.37
T_1	0.88	0.40	0.21	1.76	0.45
T_2	0.91	0.46	0.22	1.96	0.47
T_3	0.87	0.48	0.21	1.86	0.47
Average	0.86	0.44	0.21	1.81	0.44
LSD (1)	0.06	0.02	0.01	0.05	0.02
LSD (2)	0.02	0.007	0.005	0.02	0.008
Interaction	*	**	**	**	**

supply, at this stage, favors survival of secondary tillers, in agreement with Scott *et al* (1977) and Power and Alessi (1978). In this work, high ear number per m^2 at harvest was not associated with a lower harvest index, suggesting that density only has a negative effect on this index when there is a competition between these yield components that determine ear weight.

Nitrogen application at the end of tillering did not modify the number of spikelets per spike, because the apex was at the terminal spikelet stage; results do not agree with Dougherty *et al* (1978). Therefore, this yield component can only be altered when N availability increases near the double ridge stage (Langer, Liew, 1973).

In this work, differences in grain yield, where originated from modifications in grain number per m^2, mentioned by many authors as the most important yield determinant (Scott *et al*, 1977; Sebillote *et al*, 1978; Evans, 1978; Spiertz, Ellen, 1978; Spiertz, 1979; Boiffin *et al*, 1981; Darwinkel, 1983). Nitrogen spraying at anthesis or post anthesis did not has any effect on grain yield and its components, in agreement with Sarandón *et al* (1986). Contrary to Coic (1960), grain weight was found to be insensitive to N spraying, being high for this cultivar; this indicates adequate weather conditions and N availability during grain filling.

In wheat and barley, an increase in nitrogen availability decreases its translocation efficiency to the grain (Neales *et al*, 1963; Andersen, Koie, 1975; Halloran, 1981). Similar results were only found in the present study when N availability increased at sowing. Nitrogen application at this stage not only increased N uptake, but also the amount of N retained in the vegetative structures at maturity. However, the high nitrogen content in stems can be due to its higher weight and not to a lower translocation to the grain.

Fertilization at sowing decreased the %N in the grain, in agreement with Fernandez and Laird (1959) who worked with low N doses at sowing. In the present experiment, despite the high N doses, greater N consumption at early developmental stages, might have later caused an N deficit which was enough to not affect grain weight but to decrease its %N.

The increase in N distribution efficiency (NHI) at maturity in plots without N at sowing confirms that N translocation to the grain is stimulated by low N availability in the soil (Singh and Anderson, 1973). However, N spraying at tillering improved both, N uptake and N partitioning efficiency to the grain, which disagrees with data obtained by Halloran (1981) working under controlled conditions. At field level N applications at tillering can improve dry matter distribution efficiency (harvest index) due to an increase of the sink (grain) and a decrease of the source (leaves, stems). Greater sink size induces great N demand by the grain, stimulating remetabolization and N translocation to the grain. When N level in the soil is a limiting factor, vegetative plant parts could not have enough N to satisfy grain demand, leading to a higher NHI and a lower grain %N. Within this context it is unlikely that a direct relationship between N distribution efficiency (NHI) and grain %N can be found. On the contrary, high soil N availability allows a response to N grain requirements, thus a high grain yield with high %N is obtained.

CONCLUSIONS

The present study showed that N applications at sowing increased grain yield due to greater tiller production. However, this increase in the vegetative fraction can cause an early N consumption leading to N deficiency at the time some yield component of the ear is defined. It decreases head weight, dry matter distribution efficiency to the grain (HI), and grain N percentage. Urea spraying at the end of tillering, as a complement of N applications at sowing modifies such a deficiency, increasing grain set, tiller survival and grain %N.

In the absence of N applications at sowing, urea spraying at the end of tillering not only increases tiller production, grain yield and harvest index, but also grain N requirements, which could not be satisfied by the translocation of the N previously stored in the vegetative structures. In this situation grain N percentage is reduced. Spraying performed at or in post anthesis does not affect yield, but increases grain %N.

To generalize these conclusions it is necessary to study the effects of foliar fertilization in several cultivars, at different doses and developmental stages upon N uptake efficiency and its relationship with yield and grain protein content.

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