Bragantia
ISSN: 0006-8705
editor@iac.sp.gov.br
Instituto Agronômico de Campinas
Brasil

FATE OF ^{15}N-UREA APPLIED TO WHEAT-SOYBEAN SUCCESSION CROP[1]

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ABSTRACT

The wheat crop in São Paulo State, Brazil, is fertilized with N, P and K. The rate of applied N (0 to 120 kg.ha^{-1}) depends on the previous grown crop and the irrigation possibility. The response of wheat to rates and time of N application and the fate of N applied to irrigated wheat were studied during two years. Residual N recovery by soybean grown after the wheat was also studied. The maximum grain productivity was obtained with 92 kg.ha^{-1} of N. The efficiency of ^{15}N-urea utilization ranged from 52% to 85%. The main loss of applied ^{15}N, 5% to 12% occurred as ammonia volatilized from urea applied on soil surface. The N loss by leaching even at the N rate of 135 kg.ha^{-1}, was less than 1% of applied ^{15}N, due to the low amount of rainfall during the wheat grown season and a controlled amount of irrigated water, that were sufficient to moisten only the wheat root zone. The residual ^{15}N after wheat harvest represents around 40% of N applied as urea: 20% in soil, 3% in wheat root system and 16% in the wheat straw. Soybean recovered less than 2% of the ^{15}N applied to wheat at sowing or at tillering stage.

Key words: Nitrogen fertilization, efficiency, ammonia, volatilization

RESUMO

DESTINO DE ^{15}N-URÉIA APLICADA EM SUCESSÃO TRIGO-SOJA

No Estado de São Paulo, a cultura do trigo é adubada, além de P e K, com N, cuja dose (0 a 120 kg ha^{-1}) depende do cultivo anterior e da possibilidade de irrigação. A resposta do trigo às doses e épocas de aplicação e o destino do N aplicado foi estudada em dois cultivos de trigo, seguidos pela soja. Também se avaliou a recuperação do N residual pela soja cultivada nas mesmas parcelas após o trigo. A produtividade máxima estimada de grãos seria obtida com a dose de 92 kg.ha^{-1} de N. A eficiência de absorção ^{15}N-uréia variou de 52% a 85%. A principal perda de N, que variou de 5% a 12%, ocorreu através de volatilização de amônia proveniente da uréia aplicada na superfície do solo. Por lixiviação foi perdido menos que 1% do N aplicado, pois a água da chuva ou da irrigação foi suficiente para molhar somente a camada do solo onde se encontrava o sistema radicular do trigo. O N residual após o cultivo do trigo correspondeu a 40% do total aplicado, posto que 20% permaneceu no solo, 3% na matéria vegetal radicular do trigo e 16% na matéria vegetal da palha do trigo, depositada sobre o solo. A soja recuperou menos que 2% do ^{15}N aplicado no solo na semeadura ou no perfilhamento do trigo.

Palavras-chave: adubação nitrogenada, eficiência, amônia, volatilização.

(1) Received for publication in March 17, 2003, and accepted in April 20, 2004.
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(5) Com bolsa de produtividade de pesquisa do CNPq.

1. INTRODUCTION

Nitrogen and water are the most common limiting factors in agricultural systems throughout the world. Wheat crops need sufficient N and available water for obtaining optimum and good quality grain yield (IAEA, 2000).

Researches carried out in São Paulo State have shown good response of wheat to the N fertilization, but it is related to the supply of water (MÉLLO JUNIOR, 1992) and the previous grown crop (INSTITUTO AGRONÔMICO, 1996). The maximum rate of N fertilization for irrigated wheat in São Paulo State is 92 $kg.ha^{-1}$, one third at seeding and two thirds at tillering stage (RAIJ et al., 1997).

The balance between the possible maximum productivity of the cultivar by supplying N and minimizing pollution of environment from excessive N application is a goal to be reached. In one side, demands for food are on increase due to the growth of population. In other side, there are environmental and ethical pressures to minimize pollution caused by fertilizers with N. The ideal achievement of N fertilization management is productivity and profit maximization with minimum pollution. However, many factors, such as weather patterns, make it difficult to achieve a suitable balance (IAEA, 2000).

It is known for a long time that, when N fertilizer is applied to soil, N suffers transformations and the fate of this nutrient depends on many factors as soil, plant environment and fertilizer (STEVENSON, 1982).

For reaching the target of efficient use of N fertilizer it is necessary a comprehensive knowledge of all factors which the N fate depends on. The joint FAO/IAEA Division implemented an international research project on the use of nuclear techniques for optimizing fertilizer application under irrigated wheat, to increase the efficient use of N fertilizers and consequently reduce environmental pollution. The co-ordinated research project aimed to investigate various aspects of N use efficiency of wheat crop under irrigation through an interregional research network of experimental sites in countries with large cultivated areas of irrigated wheat (IAEA, 2000). The wheat grain yield response to the N fertilization and N recovery by wheat plant varied from site to site, even between sites of the same country. The N recovery by wheat plant of the first of third split of N application (applied at planting) was usually less than the second two third split application applied at tillering (IAEA, 2000). The data of most studies on fertilizer N efficiency using ^{15}N labelled fertilizers have shown that at harvest it generally range from 20% to 80%.

These variation are probably arisen from the interaction between factors such as form of fertilizer, time of application, type of soil and climatic conditions (RECOUS et al al., 1988b).

The main losses of N from urea are the nitrate leaching in soil, denitrification and ammonia volatilization. Nitrate leaching from fertilizer from the wheat rooting zone was observed in three countries out of ten, in experiments carried out in sandy or clay soils (IAEA, 2000). Nitrogen loss from the one soil was high as 57%, whereas average loss in the other soil was 17%. In others experiments, as Recous et al. (1988a), leaching loss of N from fertrilizer appeared negligible, since only trace of inorganic N was measured in the subsoil, between 30 and 120 cm.

Part of N fertilizer applied remains in the soil after the grain harvest, immobilized by soil microorganisms, in the root systems and in the wheat straw. There is a lack of data on the recovery by the subsequent crop of this N.

There were some studies in Brazil using ^{15}N in wheat crop at late 1960's and early 70's. These studies were carried out under a co-ordinated research project sponsored by International Atomic Energy Agency (IAEA) with the objective of studying the efficiency of different N sources (urea, ammonium sulphate and ammonium nitrate). Experiments were carried out in field conditions and allowed to conclude that the efficiency of the N utilization ranges from 5 to 27% with a quite similar response to all N sources, depending on the time of application (MURAOKA, 1973). Another study showed that the N fertilizer applied at seeding or at tillering stages yielded similar efficiency (BOARETTO, 1974). These results were obtained in wheat crops without irrigation.

This work presents data of N dynamic in double crop wheat-soybean and soil fertilized with different rates of urea under irrigation.

2. MATERIAL AND METHODS

The experimental site is located at the IAC research farm, Campinas, in São Paulo State (latitude = 22º54'S and longitude = 47º05'W), 674 m above sea level. The soil of the experimental site is a Dark Red Latosol (Eutrudox), with a V=54%, high P and K contents and 28 $g.kg^{-1}$ of organic matter. The previous crop grown in the experimental area was soybean. The experiments were conducted in 1995 and 1996, in two places of the same site. Treatments are shown in table 1, and rainfall and temperature variations on the site, in both years, are shown in table 2. Four replicates of each treatment were distributed in randomized blocks design.

Table 1. Nitrogen rates and time of application to wheat crop in 1995 and 1996

1995		1996	
Sowing	Tillering (1)	Sowing	Tillering
kg.ha^{-1} of N		kg.ha^{-1} of N	
0	0	0	0
10 *	20 *	15	30
20 *	40 *	30 *	60 *
30 *	60 **	45 *	90 **
40 *	80 *	60	120

* ^{15}N as urea was applied at sowing and at tillering in the different micro-plots.
** ^{15}N as urea was applied at sowing and at tillering in the same micro-plots
([1]) 5-6 Feeks scale.

Table 2. Rainfall and temperature during the wheat growing season

Month	Rainfall		Lowest temperature		Highest temperature	
	1995	1996	1995	1996	1995	1996
	mm		°C			
June	33	40	12.6	11.1	24.8	25.3
July	20	5	14.1	11.1	25.8	24.7
August	1	27	15.1	14.0	29.1	28.6
September	69	159	15.4	15.6	27.8	26.6
October	174	163	16.6	17.5	27.1	28.6
Total	297	394	-	-	-	-

Urea, triple superphosphate and potassium chloride were applied at seeding of wheat (cultivar IAC 24) in the planting furrow under the seeds and part of urea was broadcast between the rows of plants at tillering stage. Labeled urea was applied at sowing and tillering stage (5-6 Feaks scale) in different micro-plots inside the plot.

Many cultivars have been used in São Paulo State, but the IAC 24 was the predominant one in 70% of cultivated area in 1995 and 1996.

The growth cycle of IAC 24 is around 130 days; it is aluminum tolerant and is recommended for both irrigated and non-irrigated conditions (INSTITUTO AGRONÔMICO, 1996). The potential yield for this cultivar under irrigation is around 5.000 kg.ha^{-1} of grain.

Sufficient water was supplied after sowing to almost saturate the soil from the surface up to 40 cm depth, following the recommendation for wheat crop. In both years irrigation took place whenever the tensiometers placed at 20 cm depth reached the value of 0.6 atm. The amount of supplied water was estimated by the amount of water evaporated from a class A tank and crop coefficient (K_c).

Measurements of SPAD values were performed in 1995, using a chlorophyll meter were performed before N was top-dressed at tillering and at anthesis stages. At tillering and anthesis stages, the SPAD measurements were performed in the second leaves with visible sheath and in the leaf flag. N content was analyzed in above ground part of wheat at tillering and in the leaf flag at anthesis stages.

After harvesting, plants were separated in straw and grain, dried at 65 ^oC and analyzed for total N and ^{15}N.

In the experiments of 1995 and 1996 the wheat straw was left over on the soil in the respective plots after the wheat harvest, and soybean (Cristalina cultivar) was sown to determine the amount of N absorbed by soybean from the fertilizer applied to wheat crop. At the end of the soybean cycle, samples of plants were harvested, dried at 65^oC, and analyzed for total N and ^{15}N.

For estimating N leaching during the wheat cycle, soil water content was monitored by mercury tensiometers installed at 20, 40, 90 and 110 cm soil depths. Soil water content, hydraulic gradient and drainage values were calculated for 50 and 100 cm soil depths.

Soil solution was extracted from 50 and 100 cm of soil depths by porous ceramic cups, which were evacuated for approximately 2 hours, twice a week. The collected soil solutions were immediately placed in glass cups and deep-frozen. Details can be found in SPOLIDORIO (1999). These samples were then analyzed for N as nitrate and ammonium (BREMNER, 1965 and BREMNER and KEENEY, 1966). Soil solution samples were prepared by micro-diffusion (BROOKS et al., 1989) and sent to IAEA Laboratory, Seibersdorf, Austria, for ^{15}N analysis.

As the urea was broadcasted at tillering stage, the volatilization of ammonia was estimated. A semi-open static type collector was used to trap the ammonia volatilized from urea, which was calibrated according to LARA CABEZAS (1987) and LARA CABEZAS and TRIVELIN (1990). As the collector has a cap, whenever the irrigation took place, equivalent amount of water applied by irrigation was put inside the collectors, but the same number of replicates without irrigation inside the collectors were maintained with the aim of evaluating the effect of irrigation on ammonia volatilization.

Wheat root system and soil were collected after wheat harvest in 1995 and before seeding of soybean (SPOLIDORIO, 1999) for estimating the N derived from fertilizer remained in soil.

3. RESULTS AND DISCUSSION

3.1 Yield of grain and straw

The data on dry matter yields of straw and grain (12% of moisture) obtained in two years of experimentation are shown in figure 1. The highest yield of grain in 1995 was obtained with the application of 92 kg ha^{-1} estimated by regression equation, but there was no effect of N application in 1996. In both years, 1995 and 1996, the yield of grain was higher than the São Paulo State average yield, which is lesser than 2 t.ha^{-1}.

Although the grain yield in 1995 was lower than the genotype potential under irrigation, around 5 t. ha^{-1}, which was almost reached in 1996. The difference on yield between the two years was probably due to the high temperatures (above 28^oC) occurred in 1995 during the ear formation stage and high insolation in this same year, reducing the IAC-24 wheat cycle. Water content in soil surface was sufficient in both years (Figure 2).

3.2 Fate of ^{15}N-urea

Wheat recovery of applied ^{15}N

The recovery of applied N was high in both years (Tables 3 and 4). Wheat N recovery depends on the time of application of urea, among others factors (STRONG, 1995). In the present case, the urea applied broadcast at tillering stage promoted higher N use compared to applied at seeding, probably due to better synchronization of applied N with the wheat requirement for this nutrient. Similar results were obtained by many others authors (IAEA, 2000; RECOUS et al., 1998ab)

Loss of N by ammonia volatilization from applied urea

Urea was applied broadcast at tillering stage, between the plant rows, without incorporation into the soil. The amount of volatilized N depends on the rate of urea application and irrigation. The values ranged from 2.8 to 4.8 kg.ha^{-1} when irrigation followed the fertilization (Figure 3), but these data increased threefold without irrigation. Considering the collector efficiency, according to LARA CABEZAS and TRIVELIN (1990), about 13% (with irrigation) and 39% (without irrigation) of the total N-urea applied at tillering stage were volatilized as ammonia (Figure 4).

RECOUS et al. (1988a) estimated a N loss of 3.1 kg.ha^{-1} when urea was applied diluted in water on soil surface cultivated with a wheat crop using a hand-sprayer and trapped the volatilized urea using a closed PVC cylinders.

However the authors commented that the closed-chamber technique used creates artificial conditions which could either underestimate or overestimate the true losses of NH_3 from urea.

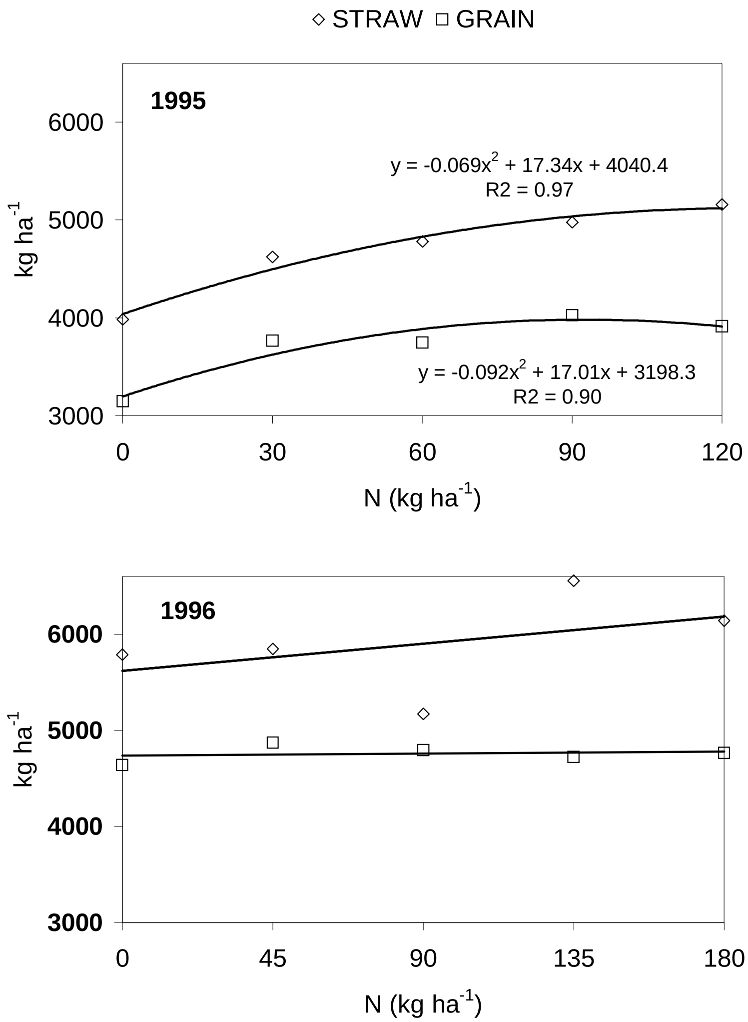

Figure 1. Effect of N rates on wheat straw and grain yield in 1995 and 1996.

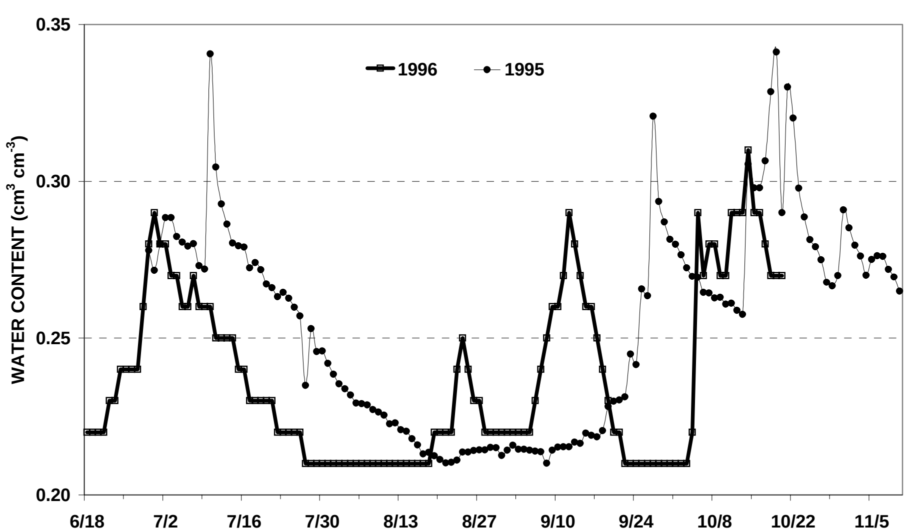

Figure 2. Soil water content at Z_r = 50 cm.

Table 3. Wheat recovery of N from urea applied at sowing and tillering - 1995

Time of application		Wheat ^{15}N recovery from applied urea				
Sowing	Tillering	Straw		Grain		Total
N rate (kg. ha^{-1})		kg.ha^{-1}	%	kg.ha^{-1}	%	
10*	20*	4.4	15	18.0	60	75
20*	40*	9.4	16	33.7	56	72
30*	60*	15.7	17	53.1	59	76
40*	80*	19.3	16	63.6	53	69

*^{15}N-urea.

Table 4. Wheat recovery of N from urea applied at sowing and tillering - 1996

Time of application		Wheat ^{15}N recovery from applied urea				
Sowing	Tillering	Straw		Grain		Total
N rate (kg.ha^{-1})		kg.ha^{-1}	%	kg.ha^{-1}	%	
30*	60	4.4	15	11,1	37	52
45*	90	9.0	20	15.7	35	55
30	60*	12.5	21	38.7	64	85
45*	90*	31.5	23	74.9	56	79

^{15}N-urea.

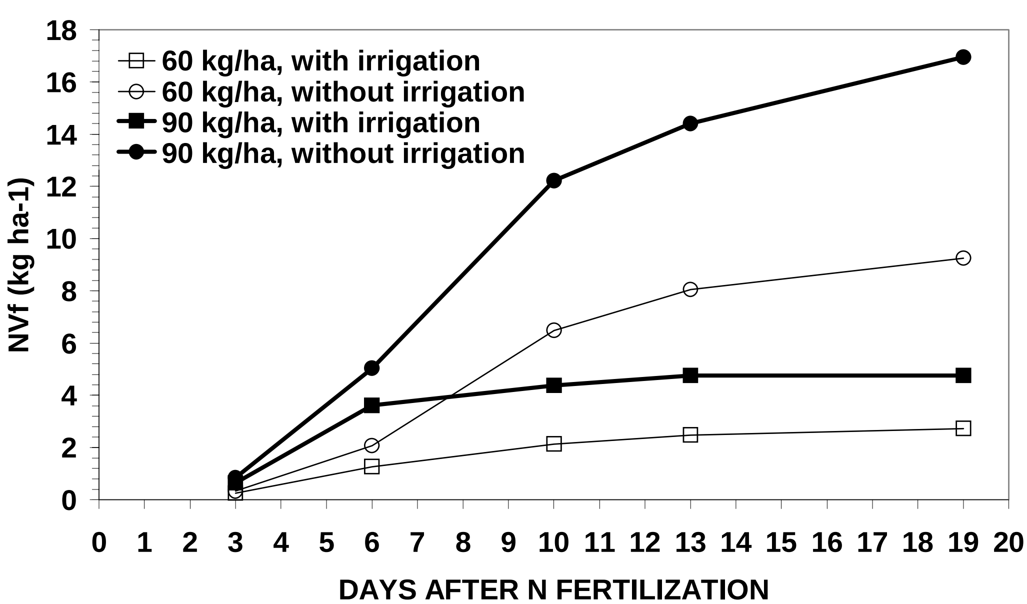

Figure 3. Cumulative N loss by ammonia volatilization from applied urea (NVf) in 1996.

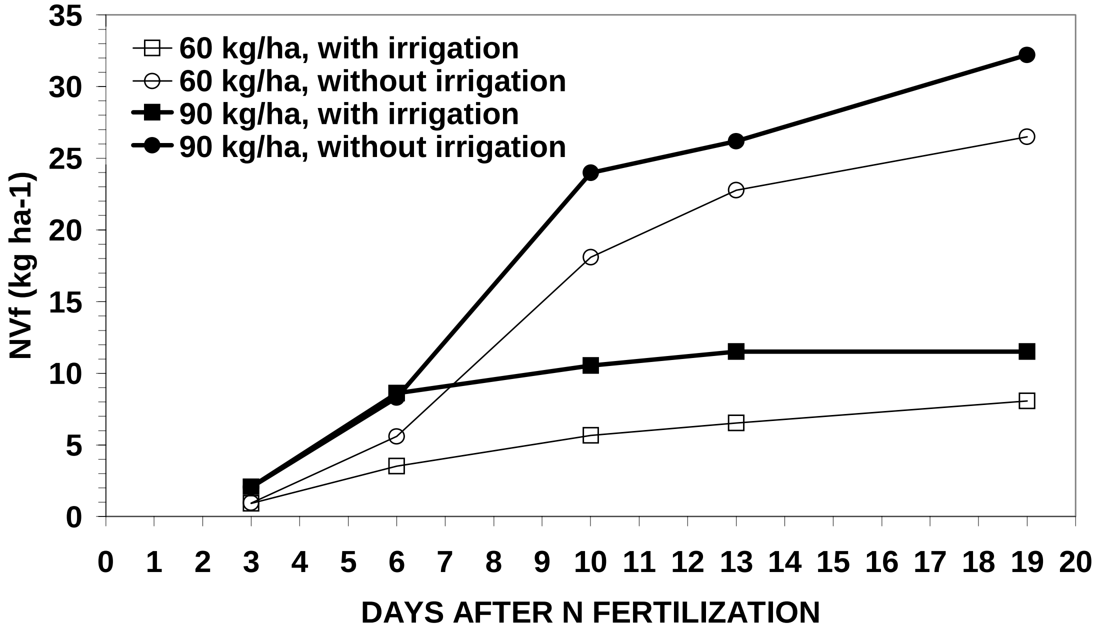

Figure 4. Cumulative N loss by ammonia volatilization from applied urea (NVf), considering the collector efficiency, in 1996.

N leaching

Nitrates in soil can be leached below the root zone together with percolating water. The quantity of water, which percolates through the soil surface and rate of applied N determine the amount of fertilizer N that can be leached within any system.

The wheat was sown in June and harvested in October, months with low rainfall. The amount of supplied water was controlled to moisten only the root zone. It is expected that such a procedure would not cause nitrate leaching below the root zone. The result of cumulative loss of nitrate at 50 cm soil depth confirms that less than 1 kg ha^{-1} of N was lost from root zone. Only a small portion (90 $g.ha^{-1}$) of it was derived from applied urea, which is around 1% of total applied N (figure 5). The data obtained from the experiment carried out in 1996 corroborated the previous year data. As these data were obtained from the plot, which received 135 $kg.ha^{-1}$ of N, the N loss by leaching would be much lower in the normal crop when less than 120 $kg.ha^{-1}$ of N is applied.

RECOUS et al. (1988a) found a negligible amount of N leached from fertilizer in a deep loamy soil.

Residual ^{15}N from applied urea in wheat root system and in the different layers of soil

The amount of N, derived from urea, that remained in the wheat root system after the harvest, for the treatment of 90 $kg.ha^{-1}$ of N as urea, in the experiment carried out in 1995, is shown in Table 5. It was less than 3% of the applied N. In the soil without roots it was found around 20% of total applied N (Table 6). As it was expected (STRONGt, 1995), the largest portion of residual N from applied urea was recovered in surface layer (0-15 cm) of soil.

N recovery by soybean growing after wheat

The wheat straw, which remained on soil after the harvest of grain, contained 25 $kg.ha^{-1}$ of N, part of it derived from N applied as urea (around 16 $kg.ha^{-1}$, in the treatment which received 90 $kg.ha^{-1}$ of N at 1995 experiment). The amount of N applied to wheat, which remained in the plots, was around 36.5 $kg.ha^{-1}$. This value, which corresponds to 40% of total applied N, can be estimated adding the amount of N remained in soil (table 5) plus the amount of N in the wheat root (table 6) and straw. Soybean recovered around 1.5 kg ha^{-1} of this N, only less than 2% of applied N to wheat or less than 4% of N from the applied urea which remained in the soil. Similar results were obtained in the 1996 experiment (table 7). According to STRONG (1995), recovery of residual N by the crops rarely exceeds 5% of the N originally applied to the previous crop. There are no reports in the literature on the recovery of N from fertilizer applied in wheat crop by soybean crop grown in succession.

Table 5. Residual N remained in wheat root system after the harvest. (Means of treatment of 90-kg.ha^{-1} of ^{15}N in 1995)

Depth	Root dry matter	N	^{15}N	Recovery
cm	kg.ha^{-1}	kg.ha^{-1}	g.ha^{-1}	%
0-5	2,860	35	2,170	2.4
5-10	1,113	13	270	0.3
20-40	135	1	50	<0.1
40-60	153	1	40	<0.1
>60	102	<1	20	<0.1

Table 6. Residual N remained in soil after the wheat harvest. (Means of treatment of 90-kg.ha^{-1} of ^{15}N in 1995)

Depth	^{15}N	Recovery
cm	g ha^{-1}	%
0-5	6,800	7.6
5-15	4,200	4.7
15-30	1,300	1.4
30-60	2,800	3.1
>60	2,900	3.2
Total	18,000	20.0

Table 7. Soybean N recovery from residual ^{15}N-urea applied to wheat

Time of application in wheat crop			N Recovery	
Sowing	Tillering	^{15}N-urea	Shoot	Root
kg.ha^{-1}		g.ha^{-1}	%	
30	60*	1,690	3	-
45*	90*	6,430	5	<1

*^{15}N.

3.3 Plant analysis for N recommendation to wheat

Nitrogen fertilization of wheat is performed in São Paulo State, part at sowing and part at tillering stage, using information of the previous crop. The methods of testing soil available N to detect previously possible response of wheat to N fertilization have proved not be useful (Raij et al., 1997).

Plant analysis of above ground parts of wheat for determination of N concentration and SPAD values should be performed in samples collected at early stages of development, at least at tillering stage, to be useful for N fertilization. Data obtained from the experiments in 1995 (table 8) and 1996 showed no correlation between N fertilization and N concentration or SPAD values at tillering stage.

Data from Vidal et al. (1999) corroborate with the present results showing that the chlorophyll meter may not be effective in predicting N deficiency at tillering stage.

Table 8. N (means of 4 replicates) and SPAD values (means of 100 replicates) at tillering and anthesis stages - 1995

Sowing	Tillering	Tillering		Anthesis	
N rate (kg.ha^{-1})		N, g.kg^{-1}	SPAD	N. g kg^{-1}	SPAD
0	0	33.1	35.73	19.0	43.73
10	20	34.4	36.10	29.1	45.55
20	40	35.4	35.58	25.6	45.65
30	60	34.3	35.58	27.3	46.18
40	80	36.5	35.70	36.4	46.50

4. CONCLUSIONS

1. The wheat response to N fertilization can not be predicted by soil or tissue analysis. The optimization of the N fertilizer applied in irrigated wheat can be reached by improving the N recovery and minimizing its possible losses.

2. To optimize the N recovery a major portion of N fertilizer should be applied at the tillering stage. In condition of São Paulo State the main loss of N occurs through ammonia volatilization from urea applied broadcast. For minimizing this loss, irrigation should be done immediately after the N fertilization. Loss of nitrate from N fertilizer by leaching beyond the root zone is very small when irrigation is technically controlled, even when N rates applied are beyond the wheat demands. Less than 5% of residual N in the soil was recovered by soybean grown after wheat.

ACKNOWLEDGMENT

To IAEA - International Atomic Energy Agency, for the financial support (project: 8087/RB).

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