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Comparison of Complete and Sulfur Coated Urea Fertilizers with Pre-plant Urea in Increasing Grain Yield and Nitrogen Use Efficiency in Wheat

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ABSTRACT

In order to increase grain yield, nitrogen use efficiency (NUE) and nitrogen apparent recovery fraction (NARF) in wheat (*Triticum aestivum* L.), this experiment was carried out with 5 or 6 treatments and 3 or 4 replications in 14 locations at 22 different sites in Iran during the 2004-05 growing season. The experiment was designed as a completely randomized block. The effect of N sources and timing on the grain yield, protein content, NUE and NARF of the current best adapted cultivars of different regions were evaluated. The treatments included T_1= the control; T_2= 150 kg ha^{-1} of N as urea in 3-split applications; T_3= 150 kg ha^{-1} of N as urea in 2-split applications; T_4= 150 kg ha^{-1} N as SCU as the base fertilizer; T_5= $^1/_3$ N as SCU as the base fertilizer +2-split urea applications and T_6=$^1/_3$ N as complete fertilizer as the base fertilizer +2-split urea applications. Protein content, NUE and NARF were calculated by measuring grain yield, N% and N-uptake. While the average grain yield and protein% for the control plots were 2,840 kg ha^{-1} and 10.03%; the yield and protein for T_2, T_3 and T_4 were 4,160 kg ha^{-1} and 11.66%; 4,278 kg ha^{-1} and 11.78%; and 3,921 kg ha^{-1} and 11.60%, respectively. Grain yield and protein content for T_5 were 4,330 kg kg^{-1} and 11.89%. Yield of 4,674 kg ha^{-1} and protein content of 12.01% were obtained by substituting complete fertilizer with 1/3 urea (T_6). The grain yield for T_6 was significantly different from T_2 for various reasons, including higher levels of available P, K, S, Zn, lower N-leaching and appropriate N-timing. NUE for T_2, T_3, T_4, T_5, and T_6 was measured to be 8.8, 9.6, 7.3, 9.9, and 12.2 kg kg^{-1}, respectively, and NARF were calculated to be 23.2, 25.3, 19.4, 26.3 and 31.6%, respectively. While the superiority of complete and SCU fertilizers over pre-plant urea has been proven, especially in the light-textured soils, it is highly recommended that the experiment be further tested and evaluated, since this practice has been increased the grain yield up to 12%, NUE up to 39 kg kg^{-1} and NARF up to 36% in comparison with the best wheat growers' N-fertilization practice.

Keywords: Complete fertilizer, NUE and NARF, Sulfur Coated Urea (SCU), Urea, Wheat, Yield.

INTODUCTIOIN

The world average cereal grain nitrogen use efficiency (NUE) and nitrogen apparent recovery fraction (NARF) are estimated at 20 kg kg^{-1} and 33%, respectively, which are far less than the 25 kg kg^{-1} and 50% figures generally reported (Raun and Johnson, 1999; Malakouti, 2004). At present, the total amount of fertilizer used in Iran is almost 4 million tons annually and, from this amount, 60% consists of N-fertilizers, mostly urea (80%) (Malakouti, 2004). When N-fertilizer is applied at rates in excess of that needed for maximum yield in cereal crops, losses through NO_3 leaching and volatilization can be significant (Jafari, 1992; Mirnia *et al.*, 1998). Mis-

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management practices in N-application constitute the main reason for lower NUE and NARF in wheat production. Low NUE is partly due to excessive rates of application of locally inexpensive and readily available N-fertilizers (Malakouti, 2005). On the basis of total farm production of 71.3 million tons of crops for 2002-03 and N-fertilizer consumption of 1.87 million tons in Iran for the same period, a NUE of 11 kg kg^{-1} was obtained for the country (Malakouti, 2004).

Over recent decades, many experiments on the effects of N-sources and rates on wheat yield have been carried out all over the world in this regard. Alcoz *et al.* (1993) found that grain yield, NUE and NARF increased with split N-application. They observed that high rates of N-application make wheat plants more susceptible to freeze damage and diseases. They also found that split N-application can be an effective tool for optimizing grain yield. Benefits from split N-application can best be realized if spring N-application is timed for the tillering stage or before and if pre-plant soil N and fall fertilizer N inputs are lowered (Sowers *et al.*, 1994). They revealed that, in the case of soils with high organic matter, even split N-application would result in very low NUE and NARF values [maximum 6.0 kg kg^{-1} and 30%, respectively, which does not correspond with the findings of Raun and Johnson (1999) who reported figures of 25 $kgkg^{-1}$ and 42 % for Europe]. Hatfield and Prueger (2004) revealed that, while there was a positive correlation between the rate of N-application and grain yield, NUE and NARF decreased with increasing N rates.

In Iran, despite many experiments carried out on the effects of N-sources, rates and timing on wheat yield, NUE and NARF were not measured in the field trials. Keshavarz (1994) studied the effects of N-fertilizer rates on the yield of winter wheat for 3 consecutive years (1991-93). The highest yield (6,551 kg ha^{-1}) and NUE (26.3 kg kg^{-1}) were obtained with 135 kg N/ha treatment. Lotfollahi (1996) reported that the recovery of fall-applied N-fertilizer was low, mainly because N-fertilizers is lost through leaching during the fall–winter seasons. In his study, Jafari (1992) found that with N-fertilizer application, crop yield increased with a NUE of 8.7 kg kg^{-1} and NARF of 26%. He concluded that, while silage corn absorbed around 27% of the applied N-fertilizer, 27% appeared as residual in soil and about 50% of the applied N-fertilizers was leached or lost in other ways. Mirnia *et al.* (1998) on determining the rates of volatilized nitrogen from urea applied in the paddy soil, revealed that, after urea broadcasting, 75% of urea volatilized from the studied plots. Khademi (1998) studied the effect of split N-application on the yield and protein content of wheat in the heavy textured soils of Shavor Research Station, Khuzestan. She found that a higher grain yield was obtained with N-split (N_{35} pre-plant + N_{34} stem elongation + N_{33} heading + N_{33} flowering) applications. Split applications of urea at the heading and flowering stages significantly increased the N uptake and protein content of the grain. Lotfollahi *et al.* (2004) observed that SCU as the base N-fertilizer increased wheat grain yield to a great extent; the NARF increased from 20% to 30%, just by substituting pre-plant urea with SCU. This change with regard to the nitrogen source is economically feasible, not only due to the improvement in NUE and the NARF, but also due to the fact that the yield of wheat grain increased by 834 kg ha^{-1} and farmers profited in terms of fertilizer costs as well as environmental protection. In another study, the effect of sources and rates of N on the yield of rainfed wheat were also evaluated by Torabi and Malakouti (1997) at Marageh Dryland Research Station. Their results revealed that N-fertilizer significantly affected grain yield and the highest yield (2,325 kg ha^{-1}) was obtained by supplying 60 kg N/ha as ammonium nitrate. While NUE for N_{40} and N_{60} was 16.5 and 17.7 kg kg^{-1}, it decreased to 12.2 kg kg-1 for N_{80}. In another experiment over a 4-year period in Maragheh rainfed region, Faizi and Valizadeh (2003) showed that the pre-plant application of 60 kg N/ha produced the highest grain yield of 1,887 kg ha^{-1} with NUE of 11.7 kg kg^{-1}, while it decreased to 6.2 kg kg^{-1} with N_{80}. The overall results demonstrated that, by increasing

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N-fertilizer, NUE and NARF were significantly decreased. While NARF was 22.5% with 60 kg N/ha, it decreased to 13.6% with 90 kg N/ha. To evaluate the substitution of complete and SCU fertilizers with a 1/3 pre-plant urea for obtaining higher grain yield, NUE and NARF, this study was conducted in 14 different locations on 22 sites during the 2004-05 growing season.

MATERIALS AND METHODS

In order to increase wheat (*Triticum aestivum* L.) grain yield, NUE and NARF, an experiment with 5 or 6 treatments and 3 or 4 replications was carried out in 14 locations at 22 sites in Iran during the 2004-2005 gowing season. These locations were: Karaj, on two different textured soils (Karaj-1 and Karaj-2); Isfahan on four locations with different salinity levels-. Roodasht, Sharifabad, Sareban and Kaboutarabad (Isfahan-1, Isfahan-2, Isfahan-3 and Isfahan-4); East Azarbyjan, on two locations-. Shabestar and Khosroshahr (E. Azarbyjan-1 and E. Azarbyjan-2); Ilam, on two locations-. Mehran and Shirvan (Ilam-1 and Ilam-2); Qom, on two different soil salinity levels (Qom-1 and Qom-2); Qazvin, on two different textured soils (Qazvin-1 and Qazvin-2); Fars, on one site (Marvdasht); Kermanshah, on one site (Mahidasht); Khorasan, on one site (Nishabour); Yazd, on one site; Lorestan, on one site (Khorramabad); Khuzestan, on one site (Shavour); West Azarbyjan, on one site (Miandoab); and Iranshahr, on one site. The physico-chemical characteristics of the studied soils were analyzed according to the Soil and Water Research Institute's conventional methods. The soils studied in the different sites were calcareous (>10% $CaCO_3$), high pH (7.8-8.1), low organic carbon (0.30-1.54%) with different clay content (18-42%) and with some degree of salinity problem (0.50- 8.00 dS m^{-1}). Studied sites were irrigated with waters that had a high level of bicarbonate (>150 mg l^{-1}). Fertilizer recommendations were based on the soil test results, except for nitrogen. The experiment was designed as a completely randomized block. In this study the effect of N sources and timing on the grain yield, protein content, NUE and NARF of the current best adapted cultivars of different regions (Pishtaz, Chamran, Roushan, Flat and Alvand) were evaluated. The treatments included T_1= the control (application of all required nutrients on the basis of soil test but without nitrogen); T_2= 150 kg ha^{-1} of N as urea in 3-split applications (pre-plant, tillering and stem elongation) which is the recommended for the best wheat growers by the Extension Office of the, Ministry of Agriculture; T_3= 150 kg ha^{-1} of N as urea in 2-split applications (tillering and stem elongation); T_4= 150 kg ha^{-1} N as sulphur coated urea (SCU) as the base fertilizer (pre-plant); T_5= $^1/_3$ N as SCU as the base fertilizer +2-split urea applications (tillering and stem elongation) and T_6= $^1/_3$ N as complete fertilizer as the base fertilizer +2-split urea applications (tillering and stem elongation). Protein content, NUE and NARF were calculated by measuring grain yield, N% and N-uptake. Finally, the plants were harvested in 10 m^2 of the plots, dried and the grain yield measured. Nitrogen use efficiency and NARF were calculated according to the procedures used by Lopez-Bellido *et al.* (2005).

NUE= [(Total grain yield in treated plot)-(total grain yield in control plot]/ (applied N)

NARF= [(Total N uptake by grain in treated plot)-(total N uptake by grain in control plot)/(applied N)] × 100.

The results were analyzed with Excel software and mean comparison tests were made by LSD calculations. Economic returns were calculated for different N-fertilizers on the basis of international prices with and without fertilizer subsidy.

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Table 1. Effects of complete and SCU fertilizers substituting pre-plant urea on wheat grain yield, protein content, NUE and NARF at 22 studied sites.

Location	Treatments	T_1 = Control (N_0)	T_2= 150 N_{Urea} (3-split)	T_3 = 150N_{urea} (2-split)	T_4= SCU substitute for total urea	T_5 = 50N_{SCU} +100N_{urea} (2-split)	T_6 = 50N_{Macro} +100N_{Urea} (2-split)
Karaj-1 Organic carbon = 0.46%, EC<1.0 dS m^{-1} and Clay = 18%	Grain yield (kg ha^{-1})	3068 C	5140 A	4519 B	4400 B	4445 B	5043 A
	Protein (%)	10.61 B	12.48 A	11.43 A	11.95 A	12.53 A	12.36 A
	NUE (kg kg^{-1})	-	12.7 AB	5.3 C	7.3 BC	8.8 B	13.6 A
	NARF (%)	-	36.1 A	26.4 BC	22.9 C	26.4 BC	34.4 A
Karaj-2 Organic carbon = 0.40%, EC<1.0 dS m^{-1} and Clay = 28%	Grain yield (kg ha^{-1})	2766 C	4576 A	2979 B	3594 B	3938 B	4927 A
	Protein (%)	9.38 B	12.13 A	11.66 A	11.78 A	12.00 A	12.36 A
	NUE (kg kg^{-1})	-	12.1 AB	1.4 C	5.5 B	7.8 B	14.4 A
	NARF (%)	-	34.0 A	10.0 D	18.9 C	24.6 B	40.1 A
Esfahan-1 Organic carbon = 0.33%, EC=7.2 dS m^{-1} and Clay = 33%	Grain yield (kg ha^{-1})	1700 B	3800 A	3053 A	3320 A	3305 A	4075 A
	Protein (%)	9.58 B	12.10 A	12.50 A	10.86 AB	9.59 B	9.30 B
	NUE (kg kg^{-1})	-	14.0 A	9.0 C	10.8 C	10.7 C	15.8 A
	NARF (%)	-	33.8 A	28.0 B	22.6 C	17.6 C	24.6 C
Esfahan-2 Organic carbon = 0.40%, EC=7.0 dS m^{-1} and Clay =45%	Grain yield (kg ha^{-1})	1342 B	3375 A	3643 A	3701 A	3225 A	3722 A
	Protein (%)	9.84 AB	10.37A	9.53 AB	10.25 A	8.19 B	9.67 AB
	NUE (kg kg^{-1})	-	13.6 B	15.3 A	15.7 A	12.6 B	15.9 A
	NARF (%)	-	24.7 B	24.5 B	28.0 A	15.0 C	26.1 AB
Esfahan-3 Organic carbon = 0.66%, EC=6.8 dS m^{-1} and Clay = 37%	Grain yield (kg ha^{-1})	2850 A	3013 A	3475 A	3075 A	3913A	3225 A
	Protein (%)	13.98 A	15.31 A	13.22 A	14.29 A	13.35A	12.70 A
	NUE (kg kg^{-1})	-	1.1 C	4.2 B	6.7 A	7.1 A	2.5 C
	NARF (%)	-	7.0 B	6.8 B	4.4 C	14.1 A	1.3 D
Esfahan-4 Organic carbon = 1.10%,EC<1.0dS m^{-1} and Clay =33%	Grain yield (kg ha^{-1})	5087 A	6210 A	6120 A	5742 A	5305 A	6340 A
	Protein (%)	11.95 A	12.12 A	13.17 A	11.90 A	11.06 A	12.99 A
	NUE (kg kg^{-1})	-	7.5 B	6.9 B	4.4 C	1.4 D	8.4 A
	NARF (%)	-	16.6 B	22.7 A	8.6 C	-2.3 D	24.7 A
E. Azarbyjan-1 Organic carbon = 0.42%, EC=2.4 dS m^{-1} and Clay = 18%	Grain yield (kg ha^{-1})	2160 D	3307 C	3526 BC	3955 AB	3917 AB	4274 A
	Protein (%)	7.17 B	10.14 A	10.38 A	10.67 A	10.96 A	10.38 A
	NUE (kg kg^{-1})	-	7.6 E	9.1 D	16.0 A	12.0 C	14.1 B
	NARF (%)	-	14.2 D	19.0 C	26.6 B	25.9 B	31.0 A
E. Azarbyjan-2 Organic carbon = 0.32%,EC=5.6 dS m^{-1} and Clay = 32%	Grain yield (kg ha^{-1})	2074 C	3580 B	3447 B	3651 B	3693 AB	4334 A
	Protein (%)	7.52 D	10.67 BC	9.62 C	11.19 B	11.89 AB	12.94 A
	NUE (kg kg^{-1})	-	10.0 B	9.1 B	10.8 B	10.5 B	14.4 A
	NARF (%)	-	14.5 C	15.0 C	19.4 B	18.5 B	25.6 A

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RESULTS AND DISCUSSION

Table 1 shows some soil chemical characteristics, such as the percentage of organic carbon, electrical conductivity and clay content as well as the effects of complete and SCU fertilizers substituting pre-plant urea on wheat grain yield, protein content, NUE and NARF in 22 wheat field locations.

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Table 1 (continued).

Location	Treatments	T_1 = Control (N_0)	T_2 = 150 N_{Urea} (3-split)	T_3 = 150N_{urea} (2-split)	T_5 = 50N_{SCU} +100N_{urea} (2-split)	T_6 = 50N_{Macro} +100N_{urea} (2-split)
Ilam-1 Organic carbon =0.80%,EC< 1.0 dS m^{-1} and Clay =32%	Grain yield(kg ha^{-1})	2548 E	3965 D	5451 C	5843 B	6289 A
	Protein (%)	7.35 C	8.81 B	9.50 AB	10.38 A	10.38 A
	NUE (kg kg^{-1})	-	9.4 C	19.4 B	22.0 AB	24.9 A
	NARF (%)	-	18.5 D	37.8 C	47.02 AB	53.2 A
Ilam-2 Organic carbon =O.45%, EC=2.2 dS m^{-1} and Clay = 24%	Grain yield(kg ha^{-1})	2236 C	3624 B	3565 B	3236 B	4365 A
	Protein (%)	7.69 C	9.62 B	10.02 A	9.50 B	10.61 A
	NUE (kg kg^{-1})	-	9.2 B	8.9 B	6.7 C	14.2 A
	NARF (%)	-	20.2 B	21.2 B	16.8 C	33.2 A
Qom-1 Organic carbon =0.50%, EC= 8.0 dS m^{-1} and Clay = 42%	Grain yield(kg ha^{-1})	1556 E	2556 D	2585 C	2739 B	2831 A
	Protein (%)	7.52 C	11.31 B	11.72 B	11.83 B	12.30 A
	NUE (kg kg^{-1})	-	6.7 C	6.9 B	7.9 B	8.5 A
	NARF (%)	-	19.0 D	21.3 C	23.7 B	26.4 A
Qom-2 Organic carbon =0.85%, EC= 2.0 dS m^{-1} and Clay = 29%	Grain yield(kg ha^{-1})	3125 E	5275 C	5188 D	5650 A	5475 B
	Protein (%)	8.22 B	9.91 A	9.74 A	9.50 A	9.85 A
	NUE (kg kg^{-1})	-	14.3 B	13.8 B	16.8 A	15.7 A
	NARF (%)	-	30.4 AB	28.4 B	32.0 A	32.3 A
Gazvin-1 Organic carbon =0.64%, EC,1.0 dS m^{-1} and Clay = 24%	Grain yield(kg ha^{-1})	3028 C	4105 B	4877 AB	4857 AB	5039 A
	Protein (%)	11.37 B	13.47 A	13.29 A	12.42 A	12.59 A
	NUE (kg kg^{-1})	-	7.2 B	12.3 A	12.2 A	13.4 A
	NARF (%)	-	23.8 A	34.8 A	29.6 A	33.2 A
Gazvin-2 Organic carbon =0.85%, EC <1.0 dS m^{-1} and Clay = 24%	Grain yield(kg ha^{-1})	3286 C	4552 B	4492 B	4746 B	5112 A
	Protein (%)	11.08 B	12.65 A	13.5 A	13.12 A	12.77 A
	NUE (kg kg^{-1})	-	8.4 B	8.0 B	9.7 B	12.2 A
	NARF (%)	-	24.2 B	28.2 A	29.6 A	33.0 A
Fars Organic carbon =0.98%,EC <1.0 dS m^{-1} and Clay = 35%	Grain yield(kg ha^{-1})	4068 B	5141 AB	5968 A	5308 AB	5701 A
	Protein (%)	10.86 A	11.19 A	11.10 A	11.80 A	11.72 A
	NUE (kg kg^{-1})	-	7.2 C	12.7 A	8.3 B	10.9 AB
	NARF (%)	-	15.4 C	25.3 A	21.1 B	25.7 A
Kermanshah Organic carbon =1.00% EC< 1.0 dS m^{-1} and Clay = 25%	Grain yield(kg ha^{-1})	3312 B	4370 AB	4241 AB	4920 A	4475 A
	Protein (%)	9.50 B	10.67 A	10.48 A	11.25 A	11.08 A
	NUE (kg kg^{-1})	-	7.0 B	6.2 BC	10.7 A	7.8 B
	NARF (%)	-	17.3 C	14.9 D	27.3 A	20.7 B
Khorasan Organic carbon =0.84%,EC=5.3 dS m^{-1} and Clay = 28%	Grain yield(kg ha^{-1})	2525 D	3636 C	4343 B	4416 B	4820 A
	Protein (%)	10.15 C	13.00 A	11.33 B	12.67 A	12.02 A
	NUE (kg kg^{-1})	-	7.4 C	12.1 B	12.6 B	15.3 A
	NARF (%)	-	25.2 B	27.6 B	35.3 A	37.6 A
Yazd Organic carbon =0.30%,EC=7.9 dS m^{-1} and Clay =21%	Grain yield(kg ha^{-1})	2101 B	2403 B	3670 A	2795 B	2872 B
	Protein (%)	8.69 C	11.54 BC	13.00 B	14.92 A	14.98 A
	NUE (kg kg^{-1})	-	2.0 C	10.5 A	4.2 B	5.1 B
	NARF (%)	-	9.0 C	27.6 A	22.4 B	23.6 B

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Different treatments, especially T_5 and T_6, significantly ($p <= 0.05$) affected the grain yield, protein content, NUE and NARF at almost all the studied sites. More frequent N applications seem necessary, which is the reason for the high NUE and NARF from T_2, T_5 and T_6. High rates of N-uptake, NUE and NARF in T_5 and T_6 are due to the application of SCU and complete fertilizers instead of pre-plant urea. The highest grain yield, NUE and NARF for T_5 and T_6 in most cases were possibly due to the fact that SCU and complete fertilizers contain other nutrients (P, K, S, and Zn) and the fact that, in

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Table 1 (continued).

Location	Treatments	T_1 = Control (N_0)	T_2 = 150 N_{Urea} (3-split)	T_3 = 150N_{urea} (2-split)	T_5 = 50N_{SCU} +100N_{urea} (2-split)	T_6 = 50N_{Macro} +100N_{urea} (2-split)
Lorestan Organic carbon =1.05% EC<1.0 dS m^{-1} and Clay =18%	Grain yield (kg ha^{-1})	4053 B	4981 AB	5534 A	4999 AB	5068 AB
	Protein (%)	13.64 B	14.08 A	14.56 A	14.11 A	14.24 A
	NUE (kg kg^{-1})	-	10.1 A	6.3 B	9.9 A	6.8 B
	NARF (%)	-	28.6 B	29.0 A	17.4 B	19.2 B
Khuzestan Organic carbon =0.94%, EC= 3.2 dSm^{-1} and Clay = 36%	Grain yield (kg ha^{-1})	3715 B	5291 A	5239 A	5187 A	5195 A
	Protein (%)	10.49B	13.96 A	13.82 A	14.17 A	14.40 A
	NUE (kg kg^{-1})	-	9.6 A	10.2 A	8.9 A	9.0 A
	NARF (%)	-	20.1 A	18.2 A	19.4 A	21.0 A
W. Azarbyjan Organic carbon = 1.18% , EC= 1.1 dS m^{-1} and Clay =29%	Grain yield (kg ha^{-1})	3428 C	4750 AB	4548 B	5069 AB	5435 A
	Protein (%)	9.62 A	7.99 B	10.73 A	10.78 A	10.38 A
	NUE (kg kg^{-1})	-	11.0 C	8.5 D	13.6 B	16.6 A
	NARF (%)	-	5.7 C	18.1 B	24.8 A	26.8 A
Iranshahr Organic carbon = 0.40, EC<1.0 dS m^{-1} and Clay =25%	Grain yield(kg ha^{-1})	2470 C	3871 AB	3660 B	3752 B	4201 A
	Protein (%)	11.75 C	13.79 AB	13.07 AB	14.12 AB	14.83 A
	NUE (kg kg^{-1})	-	9.3 B	7.9 C	8.6 AB	11.5 A
	NARF (%)	-	28.1 B	21.6 C	27.4 B	38.0 A

heavy-textured soils, possibly any nitrogen released as NH_4^+ was adsorbed by clay particles resulting in lower rates of loss from leaching. In particular, NUE and NARF under ideal conditions with 3-split applications of urea in the aridisols and entisols of Iran were reported to be around 9 kg kg^{-1} and 22% as compared to a value of 20 kg kg^{-1} and 33% for developed countries, respectively (Malakouti, 2004). These NUE and NARF values agreed with those found by Keshavarz (1994), Lotfollahi *et al.* (2004), Malakouti (2005) and McNeill *et al.* (2005).

While the average grain yield and protein percentage for the control plots (T_1) at 22 sites were 2,840 kg ha^{-1} and 10.03%, respectively, the yield and protein for T_2, T_3 and T_4 amounted to: 4,160 kg ha^{-1} and 11.66%; 4,278 kg ha^{-1} and 11.78%; 3,921 kg ha^{-1} and 11.60%, respectively. Grain yield and protein content for T_5 (substituting SCU for 1/3 pre-plant urea) were 4,330 kg kg^{-1} and 11.89%. By substituting complete fertilizer for 1/3 urea (T_6), a yield of 4,674 kg kg^{-1} and 12.01% protein were obtained (Figure 1). NUE for T_2, T_3 and T_4 were 8.8, 9.6 and 7.3 kg kg^{-1} and calculated NARF were 23.2, 25.3 and 19.4. However, when 1/3 of urea was substituted by SCU, NUE and NARF increased to 9.9 and 26.3% and, when 1/3 urea was substituted by complete fertilizer; values of 12.2 and 31.6% were obtained for NUE and NARF, which were statistically significant at most of the studied sites (Figure 2).

In spite of the fact that urea was used in 3-split applications (pre-plant, tillering and stem elongation), NUE and NARF were low mainly due to heavy irrigation and high precipitation during the fall-winter period. It seems more logical to substitute 1/3 urea with SCU or with complete fertilizer for use in pre-plant application, irrespective of the physicochemical properties of soil. The data from our experiment results revealed that, T_6 was the best of all the studied sites. The second best treatment compared with control was T_5, where 1/3 of nitrogen was applied as SCU pre-plant and the other 2/3 as a 2 side dressing of urea, whereas in (T3) all of the urea was used in 2-split applications. Applying all N as SCU pre-plant (T_4) produced low yield, low NUE and NARF values, and therefore, is not to be recommended. It should be pointed out that no consideration has been given to the residual effects of P, K, S and Zn added pre-plant in T_6 or to the effects of S in T_5.

Despite the fact that the more efficient fertilizer management practices such as split application were used, and slow nitrogen releasing SCU and complete fertilizers were

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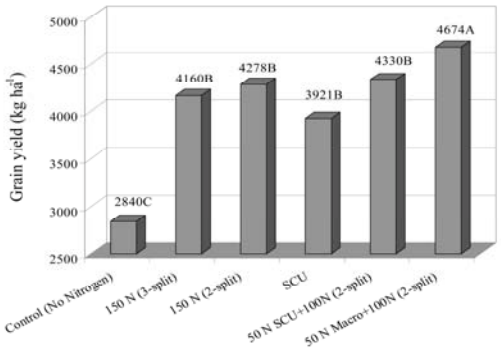

Figure 1. Effect of complete and SCU fertilizers substituting pre-plant urea on grain yield in 22 studied sites. [a]

[a] LSD for grain yield=346 kg ha^{-1} and protein= 0.82%

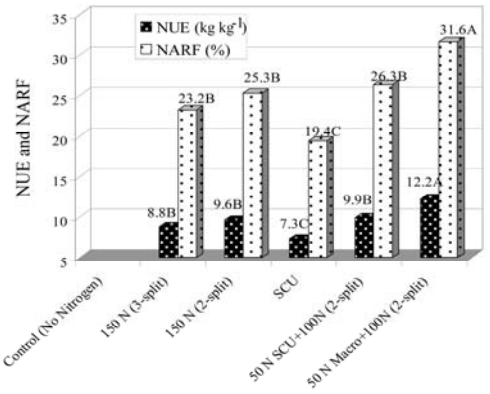

Figure 2. Effect of complete and SCU fertilizers substituting pre-plant urea on NUE and NARF in 22 studied sites.

substituted for $^1/_3$ of urea (pre-plant), the average values for NUE were calculated as 8.8 (T_2), 9.6 (T_3), and 12.2 (T_6) kg kg^{-1}, respectively, for the three selected fertilizer treatments. NUE was even lower in T_4 (SCU completely substituted for urea). The values are still much lower than the average NUE of 20 kg kg^{-1} reported by Raun and Johnson (1999). It was concluded that, while NARF is 29% for cereals, it is low in our country with wheat production mainly as a result of ineffective N-fertilizer use, poor application and irregular timing of N-fertilizers.

According to the Bureau of Statistics and Information Technology Annual Report (2004), the average cost of producing wheat in irrigated farms with a yield of 3,254 kg ha^{-1} was calculated to be 2.52 million rials in 2002. The rate of fertilizer application in irrigated wheat was reported to be 355 kg ha^{-1}. Assuming that subsidized fertilizer costs about 400 rials per kg, then the cost of fertilizer would be to 5.6% of the total cost of production of 3,254 kg of wheat grain per hectare. However, if subsidies were to be eliminated, the fertilizer costs would amount to 26% of the total cost. Obviously, in this case the total cost would be more than 3 million rials instead of 2.52 million rials. The economic returns for these substitutions, even without considering any fertilizer subsidies, turned out to be 3.4, 3.7, 1.6, 3.0 and 3.1 rials for the respective treatments based on international prices of fertilizers (Table 2), but the returns improved to 18.0, 19.6, 9.8, 17.4 and 19.6, respectively, when fertilizer subsidies were included according to 2004 prices (Table 3).

Results of research on different soils with different organic matter content, texture, salinity and climate showed that, in irrigated wheat, the substitution of 1/3 pre-plant urea with SCU and complete fertilizers had positive results. In addition to a grain yield increase of 11% with T_6 in comparison with T_2, the NUE and NARF increased up to 28 and 26% in T_6. Most importantly, variations in NUE and NARF with regard to soil type, texture and organic content were also seen in this experiment. More research is needed to identify economical methods of improving the recovery rate of N-fertilizers taking into consideration the fact that the physico-chemical properties of the soils of wheat growing regions are different. In general, the application of urea even with 3-spilt application (pre plant, tillering and stem elongation) in irrigated wheat does not increase NUE due to leaching of pre-plant N in the fall and winter so, by applying SCU pre-plant instead of 1/3 urea, this will increase NUE and NARF.

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Complete fertilizer also increased NUE and NARF due to having extra P, K and Zn.

CONCLUSION

Most of the scientific research conducted in Iran until the end of 20th century was concerned with the effects of sources, rates and the timing of N-fertilizers on wheat grain yield and quality. However, in the third millennium, due to environmental and economic concerns, the challenge of increasing NUE and NARF was addressed and taken into consideration. Since the farmer's conventional fertilization practice is mostly the application of N and P fertilizers without using soil testing analysis results the use of urea, which constitutes 80% of the 2.6 million tons of annual N-fertilizers use, is done with no consideration given to NUE and NARF because of heavily subsidized fertilizer prices. This experiment was carried out in 14 locations at 22 sites in the main wheat growing regions of the country.

Despite the fact that the more efficient fertilizer management practices such as split application, SCU and complete fertilizers were substituted for $^1/_3$ of urea (pre-plant), the average grain yield and protein content of wheat were 4,674 kg ha^{-1} and 12.01% for the T_6 treatment, and the yield and protein content were 2,840 kg ha^{-1} and 10.03%, respectively, for the control (T_1). NUE values were 8.8, 9.9, and 12.2 kg kg^{-1} for T_2, T_5 and T_6, respectively. The NARF for T_2, T_5 and T_6 were 32.2, 26.3 and 31.6%, respectively. Despite the fact that the application of complete and SCU fertilizers instead of pre-plant urea gave higher NUE and NARF, these figures are still much lower than the expected average NUE and NARF of 20 kg kg^{-1} and 50%. The highest values of grain yield, NUE and NARF were obtained with T_6 by applying 1/3 of nitrogen as the base fertilizer in the form of complete fertilizer, and the remaining 2/3 as two top dressings of urea. The NUE and NARF values varied from 7.3 to 12.2 kg kg^{-1} and from 19.4% to 31.6%, respectively. The maximum recovery rates were obtained with T_5 and T_6 at most of the studied sites. In addition to yield increases of 4% and 12% with T_5 and T_6, the NUE increased up to 12 and 15 kg grain/kg N and NARF values improved to 39 and 36%, for T_5 and T_6, respectively. The results obtained revealed that there was no significant difference between the T_2 and T_6 treatments, although the T_6 treatment resulted in higher grain yield and protein content.

The economic returns for these substitutions, without considering any fertilizer subsidy, turned out to be: 3.4 under optimum conditions (T_2); 3.7 for T_3 (urea in 2-split

Table 2. Rate of economic returns in rials based on international prices of fertilizers and wheat grain.[a]

Fertilizer treatments	Grain yield (kg ha^{-1})	Additional wheat grain (kg)	Amount of fertilizer application (kg ha^{-1})	Fertilizer costs (1000 rials)[b]	Income from additional wheat (1000 rials)	Rate of monetary return (rials)
T_1 = Control (N_0)	2840 C	-	-	-	-	-
T_2 = 150 N_{Urea} (3-split)	4160 B	1320	326 Urea	777.5	2. 640	3.4 A
T_3 = 150N_{urea} (2-split)	4278 B	1438	326 Urea	777.5	2.876	3.7 A
T_4= SCU *substitute* with total urea	3921 B	1081	426 Urea	1341.9	2.162	1.6 B
T_5 = 50N_{SCU} + 100N_{urea} (2-split)	4330 AB	1490	142 SCU+217 Urea	964.8	2.980	3.0 A
T_6 = 50N_{Macro} +100N_{urea} (2-split)	4674 A	1834	333 Marco +217 Urea	1176.9	3.668	3.1 A

[a] The international prices for urea, sulfur coated urea, complete fertilizer and wheat grain are 2,385; 3,150; 1,980 and 2,000 rials per kg, respectively.

[b] 1 US dollar is 9000 rials.

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Table 3. Rate of economic returns in rials based on subsidized fertilizer prices.[a]

Fertilizer treatments	Grain yield (kg ha^{-1})	Additional wheat grain (kg)	Amount of fertilizer application (kg ha^{-1})	Fertilizer costs (1000 rials)	Income from additional wheat (1000 rials)	Rate of monetary return (rials)
T_1 = Control (N_0)	2840 C	-	-	-	-	-
T_2 = 150 N_{Urea} (3-split)	4160 B	1320	326 Urea	146.7	2,640	18.0 A
T_3 = 150N_{urea} (2-split)	4278 B	1438	326 Urea	146.7	2,876	19.6 A
T_4= SCU substitute with urea	3921 B	1081	426 Urea	221.5	2,162	9.8 B
T_5 = 50N_{SCU} + 100N_{urea} (2-split)	4330 AB	1490	142 SCU+217 Urea	171.5	2,980	17.4 A
T_6 = 50N_{Macro} +100N_{urea} (2-split)	4674 A	1834	333 Marco +217 Urea	187.5	3,668	19.6 A

[a] The internal (subsidized) prices for urea, sulfur coated urea, complete fertilizer and wheat grain are 450; 520; 570 and 2,000 rials per kg, respectively.

applications); 1.6 for T_4 (N as SCU as the base fertilizer); 3.0 by substituting 1/3 pre-plant urea with SCU (T_5); and 3.1 by substituting 1/3 urea with complete fertilizer as base fertilizer (T_6). If fertilizer subsidies were included, the returns would increase to 18.0, 19.6, 9.8, 17.4 and 19.6, respectively.

In order to improve NUE in areas that have soils with different textures and various salinity levels, one third of the N requirement of wheat should be in the form of complete fertilizer or SCU and the remaining two-thirds as side dressings of urea. The results obtained demonstrated that due to a) the existence of long wet seasons in the fall and winter, b) heavy irrigation after wheat planting in the early fall, c) extra nutrients such as P, K, S and Zn in the complete and SCU fertilizers and the lower dissolution rate in the SCU, application of 1/3 recommended urea in the wheat pre-plant period is not advisable because of high N leaching. In order to reduce N loss, it is therefore, recommended that instead of the application of 1/3 pre-plant urea, SCU or complete fertilizer should be used. Despite the proven superiority of complete and SCU fertilizers over pre-plant urea, especially in lightly textured soils, it is strongly recommended that this finding be substantiate in some important wheat growing provinces of Iran, since this practice increases the wheat grain yield up to 12%, NUE up to 39% and NARF up to 36% in comparison with the best wheat growers' current N-fertilization practice.

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مقایسه کودهای کامل و اوره با پوشش گوگردی با اوره قبل از کاشت در افزایش عملکرد دانه و کارآیی مصرف نیتروژن در گندم

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چکیده

به منظور افزایش کارآیی (NUE) و درصد بازیافت (NARF) نیتروژن در گندم (*Triticum aestivum* L.) آزمایش حاضر با ۵ یا ۶ تیمار کودی و ۳ یا ۴ تکرار در ۲۲ مزرعه گندم در مناطق مختلف کشور در سال زراعی ۸۴-۱۳۸۳ پیاده گردید. طرح آزمایشی در کلیه مناطق تحت بررسی بلوکهای کامل تصادفی بود. در این تحقیق، اثر منابع نیتروژنه و زمان مصرف در عملکرد، پروتئین، کارآیی نیتروژن و درصد بازیافت نیتروژن با استفاده از بهترین ارقام معرفی شده در هر منطقه انجام گرفت. تیمارها عبارت بود از: تیمار اول= شاهد؛ تیمار دوم= مصرف ۱۵۰ کیلوگرم در هکتار نیتروژن از منبع اوره با عرف زارعین پیشرو؛ تیمار سوم= مصرف ۱۵۰ کیلوگرم در هکتار نیتروژن از منبع اوره در ۲ تقسیط سرک ؛ تیمار چهارم: مصرف ۱۵۰ کیلوگرم نیتروژن به صورت پایه از منبع اوره باپوشش گوگردی(SCU)؛ تیمار پنجم= یک سوم نیتروژن از منبع SCU به صورت پایه + دو سرک اوره و تیمار ششم = یک سوم نیتروژن از منبع کود کامل ماکرو به صورت پایه + دو سرک اوره تأمین گردید. عملکرد دانه، پروتئین، NUE و NARF از طریق کیل‌گیری، تعیین و درصد نیتروژن دانه گندم و میزان جذب نیتروژن محاسبه گردید. میانگین عملکرد هکتاری و درصد پروتئین در ۲۲ مزرعه در قطعات شاهد به ترتیب برابر ۲۸۴۰ کیلوگرم در هکتار و ۱۰/۰۳ درصد تعیین گردید. میانگین این ارقام در تیمار دوم ۴۱۶۰ و ۱۱/۶۶؛ در تیمار سوم ۴۲۷۸ و ۱۱/۷۸، در تیمار چهارم ۳۹۲۱ و ۱۱/۶۰، در تیمار پنجم ۴۳۳۰ و ۱۱/۸۹ و در تیمار ششم ۴۶۷۴ کیلوگرم در هکتار و ۱۲/۰۱ درصد بدست آمد. عملکرد در تیمار ششم با تیمار دوم به دلایل متعددی من جمله زیادی فسفر، پتاسیم، گوگرد و روی در کود کامل ماکرو،آبشویی کم و زمان مناسب مصرف نیتروژن در کود اوره با پوشش گوگردی، اختلاف معنی‌داری داشت. NUE برای تیمارهای دوم، سوم، چهارم و پنجم به ترتیب ۸/۸، ۹/۶، ۷/۳، ۹/۹ و ۱۲/۲ کیلوگرم در کیلوگرم و NARF در این تیمارها به ترتیب ۲۳/۲، ۲۵/۳، ۱۹/۴، ۲۶/۳ و ۳۱/۶ درصد تعیین گردید. با وجود اثبات ارجحیت جایگزینی کودهای کامل ماکرو و SCU بر اوره قبل از کاشت خصوصاً در خاکهایی با بافت سبک، تعمیم این طرح به چند استان مهم گندم خیز کشور اکیداً توصیه می‌گردد. چه با اعمال این روش، در مقایسه با بهترین تیمار کودی نیتروژنه که توسط زارعین پیشرو در حال اجراست، عملکرد گندم تا ۱۲ درصد، NUE تا ۳۹ کیلوگرم در کیلوگرم و NARF تا ۳۶ درصد افزایش می‌یابد.

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