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Agronomic efficiency and grain yield response index of wheat varieties as influenced by nitrogen rates in semi-arid zone of southern Niger

Abdelkader M. S.[1]*, Auwalu B. M.[2] and Mohammed I. B.[2]

[1]National Institute for Agricultural Research of Niger (INRAN), Niger.
[2]Department of Agronomy, Bayero University, Kano, Nigeria.

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Wheat productivity in southern Niger is hampered by the utilization of local wheat varieties that exhibit a low response to fertilizer. A field experiment was conducted over two dry seasons in Djirataoua to investigate the efficiency and responsiveness of four wheat varieties under four nitrogen doses (0, 100, 150 and 200 kg N ha^{-1}). The experiment followed a split-plot design with three replications. Results revealed an increase in grain yield with rising nitrogen rates, peaking at 150 kg N ha^{-1}. The wheat varieties exhibited varying responses to nitrogen, with Reyna-28 demonstrating higher grain yield and the local variety showing lower productivity. The most substantial grain yield was observed with the interaction of Reyna-28 and 150 kg N ha^{-1}. Sokoll/3/ exhibited the best agronomic efficiency with the application of 100 kg N ha^{-1}. The grain yield response index indicated that Reyna-28 was more efficient in nitrogen utilization, Sokoll/3/ was more responsive to nitrogen increase, while the local variety displayed neither efficiency nor responsiveness to nitrogen. Based on these findings, the recommended practice for maximizing wheat grain yield in this area is the application of 150 kg N ha^{-1}, coupled with the use of Reyna-28.

Key words: *Triticum aestivum*, low-N, high-N, N-utilization, yield.

INTRODUCTION

Soils in Niger Republic are notably deficient in nitrogen, leading to low crop productivity (Kiari and Ichaou, 2016; Henao and Baanante, 2006). In the Djirataoua valley, farmers typically cultivate local wheat varieties under irrigation during the dry season. The application of fertilizers on wheat farms is often carried out without scientific knowledge, resulting in low efficiency, higher costs, and environmental problems. Farmers in this region predominantly grow local cultivars due to the lack of improved wheat varieties. Wheat is highly responsive to nitrogen fertilization and particularly sensitive to insufficient nitrogen. For irrigated wheat, Heinemann et al. (2006) observed a positive response of up to 156 kg ha^{-1} of N, resulting in a grain yield of 6472 kg ha^{-1} in

*Corresponding author. E-mail: mkader1277@gmail.com.

Table 1. Physical and chemical properties of the soil of the experimental site at 0-25 cm depth during 2016-2017 dry season at Djirataoua, Niger Republic.

Particle size distribution (g kg^{-1})	Value
Physical properties	
Sand	510.60
Silt	327.70
Clay	161.60
Texture	Loamy
Water holding capacity (%)	57.2
Chemical properties	
pH (H_2O)	6.62
pH ($CaCl_2$)	6.06
Organic Matter (g kg^{-1})	9.94
Nitrogen NH_4^+ (g kg^{-1})	0.05
Nitrogen NO_3^- (g kg^{-1})	0.02
Total Nitrogen (g kg^{-1})	1.05
Available Phosphorus (mg kg^{-1})	5.94
Exchangeable cations (Cmol kg^{-1})	
K	0.26
Na	0.38
Ca	1.15
Mg	1.18
CEC	3.30

Source: Soil Laboratory, Department of Soil Science, Bayero University, Kano.

Brazil. Research conducted by Falaki and Mohammed (2011) in northern Nigeria, ecologically similar to southern Niger Republic (William, 2005), indicated that the positive response to nitrogen varies among wheat cultivars. Expanding research on cultivars with high nitrogen absorption and low fertilizer requirements would be appropriate to develop cultivars that efficiently absorb and utilize nitrogen in grain production (Le Gouis et al., 2000). The Grain Yield Response Index (GYRI) serves as an indicator of the efficiency of wheat cultivars in producing higher grain yields at low nitrogen rates and their response to increased nitrogen fertilizer rates. Additionally, the efficiency of nitrogen usage in cereal crops is calculated by Agronomic Efficiency (AE), reflecting the direct production impact of applied nitrogen fertilizer (Fixen et al., 2014). The present study was conducted on clay-loamy soil in southern Niger to identify genotypes with high response and/or efficiency to different nitrogen levels among selected wheat varieties.

MATERIALS AND METHODS

The field experiment was conducted during the 2016/2017 and 2017/2018 dry and cold seasons in southern Niger Republic, specifically at Djiataoua (13° 25' 59" North and 7° 8' 12" East) on clay-loamy soil. The physical and chemical properties of the experimental site are shown in Table 1. The treatments consisted of the factorial combination of four wheat varieties (El Kodaraoua as a local check, Norman, Reyna-28, and Sokoll/3/) and four levels of nitrogen fertilization (0, 100, 150, and 200 kg N ha^{-1}), arranged in a split-plot design with three replications. The main plots were allocated for N fertilizer levels, while the wheat varieties were randomly arranged in sub-plots. The unit plot area was 2.4 m^2, consisting of four rows of 2 m in length and 30 cm apart.

Two central rows with a net plot size of 1.2 m^2 were used for data collection. To prevent pests and diseases, seeds were treated with the chemical "Calthio" at the rate of 10 g kg^{-1} of seed. No pests were observed during both seasons. Sowing was done using a single-row hand drill on November 25, 2016, during the 2016/2017 dry season and on November 13, 2017, during the 2017/2018 dry season. The plots were irrigated weekly at 30 mm per irrigation throughout the growing season. Fertilizers were applied in the form of NPK (15-15-15), SSP (0-18-0), and Urea (46-0-0). Nitrogen fertilizer was applied at various levels (0, 100, 150, and 200 N kg.ha^{-1}) in a single application at the first node emergence stage (jointing stage).

Parameters of study

Grain yield (GY)

Data were collected on various agronomic parameters, but the most important one that was used in this publication is the grain yield measured on the central rows.

Table 2. Mean value of grain yield (kg ha^{-1}) as affected by Nitrogen rates, variety and interaction Nitrogen × Variety in 2016/2017 and 2017/2018.

Treatments	**Grain yield (kg ha^{-1})**	
	2016/2017	**2017/2018**
Nitrogen level (kg ha^{-1})		
0	596^{c}	1461^{c}
100	2786^{b}	2354^{b}
150	3202^{a}	2500^{ab}
200	3106^{ab}	2719^{a}
LSD (0.05)	*326*	*348*
Variety		
Local Check	1825^{c}	1846^{c}
Sokoll/3/	2701^{a}	2584^{b}
Norman	2322^{b}	1690^{c}
Reyna-28	2842^{a}	2914^{a}
LSD (0.05)	*231.1*	*237.6*
Interactions		
Nitrogen x variety	0.004**	0.004**

Means in the same column followed by the same letter (s) are not significantly different at 5% level of probability using Fisher's LSD.

Agronomic efficiency (AE)

The efficiency of nitrogen usage in cereal crop is calculated by Agronomic Efficiency (AE). In this study, the AE was calculated according to Delogu et al. (1998) using the following equation:

$$\text{GYRI} = \frac{\text{Grain yield under high N level} - \text{Grain yield under low N level}}{\text{High N level} - \text{Low N level}}$$

Grain yield response index (GYRI)

The GYRI is an indication of the efficiency of wheat cultivars for producing higher grain yield at low N rates and their response to increase N fertilizer rates. In this study, the GYRI was calculated for each cultivar, according to Fageria et al. (1981) using the following equation:

$$\text{AE (kg grain per kg N)} = \frac{\text{Grain yield at N treatment} - \text{Grain yield at zero N}}{\text{Applied N at N treatment}}$$

According to GYRI, the wheat varieties can be classified into four groups: (1) efficient and responsive (ER) that produces high grain yield at low as well as high rates of N fertilizer; (2) efficient and not responsive (ENR) that produces high grain yield at low N rate with lower response to increased N fertilizer; (3) not efficient but responsive (NER) that has low grain yield at low nitrogen rate but responds well to increased N fertilizer; and (4) neither efficient nor responsive (NENR) that has low grain yield at low nitrogen rate and low response to increased N fertilizer. In this study, the GYRI was calculated at 0 kg N ha^{-1} as low N level and 200 kg N ha^{-1} as high N level.

Statistical analysis

Data on grain yield were subjected to the analysis of variance (ANOVA) using the software GENSTAT 18th Edition and mean comparison was done using Fisher protected LSD at 5% level of probability.

RESULTS AND DISCUSSION

Effects of N fertilizer rate on grain yield

The impact of nitrogen (N) fertilizer rate on grain yield (GY) was highly significant during both seasons (Table 2). In the 2016/2017 season, the highest GY was recorded with the application of 150 kg N ha^{-1} (3202 kg ha^{-1}) and 200 kg N ha^{-1} (3106 kg ha^{-1}), which were statistically at par. The lowest GY (596 kg ha^{-1}) was observed in the control treatment (0 kg N ha^{-1}). Similarly, in the 2017/2018 season, the application of nitrogen at 150 and 200 kg N ha^{-1} resulted in the highest GY, with 2500 and 2719 kg ha^{-1}, respectively. The lowest GY (1461 kg ha^{-1}) was recorded at 0 kg N ha^{-1}. Overall, the trend of results indicated an increase in wheat GY from the non-fertilized plots (0 kg N ha^{-1}) up to 150 kg N ha^{-1}, beyond which no significant increase in GY was observed. This suggests that the application of 150 kg N ha^{-1} provides a well-balanced supply of nitrogen, resulting in higher net assimilation rate and increased grain yield. In line with this, Heinemann et al. (2006) reported a positive and highest response of grain yield up to 156 kg ha^{-1} of nitrogen for irrigated wheat. Similarly, Zhu and Wen (1992) found and recommended the range value of 150 to 180 kg N ha^{-1} as the optimum dose for wheat production.

Table 3. Interaction Nitrogen rates x Variety on GY (kg ha^{-1}) of wheat at Djirataoua in 2016/2017 and 2017/2018.

Treatment	Variety			
	El-Kodaraoua	Sokoll/3/	Norman	Reyna-28
Nitrogen level (kg ha^{-1})	**2016-2017**			
0	404^{g}	637^{g}	551^{g}	793^{g}
100	2238^{f}	3094^{cd}	2468^{ef}	3342^{bcd}
150	2465^{ef}	3652^{ab}	3327^{bcd}	3364^{a-d}
200	2192^{f}	3422^{abc}	2944^{de}	3867^{a}
LSD (0.05)	505.5			
Nitrogen level (kg ha^{-1})	**2017-2018**			
0	1171^{hi}	1406^{hi}	988^{i}	2281^{def}
100	2002^{fg}	2750^{cd}	1593^{gh}	3073^{abc}
150	2246^{df}	2843^{bc}	2174^{f}	2736^{cde}
200	1965^{fg}	3338^{ab}	2006^{fg}	3566^{a}
LSD (0.05)	527.5			

Means followed by the same letter (s) are not significantly different at 5% level of probability using Fisher's Least Significant Difference.

Varietal differences in grain yield

The wheat varieties exhibited significant differences in grain yield (GY) during both dry seasons (Table 2). In the 2016/2017 season, the results showed the best performance of varieties Reyna-28 and Sokoll/3/ in GY, producing 2842 and 2701 kg ha^{-1}, respectively. The lowest grain yield was recorded by the local variety El-Kodaraoua (1825 kg ha^{-1}). In the 2017/2018 dry season, Reyna-28 was the most productive cultivar in terms of GY, yielding 2914 kg ha^{-1}, followed by Sokoll/3/ with 2584 kg ha^{-1}. Norman and El-Kodaraoua produced the lowest grain yields, recording 1690 and 1846 kg ha^{-1}, respectively. The overall trend indicated that the grain yield of the studied wheat cultivars varied significantly during both dry seasons. This variation may be attributed to the genetic potential of these cultivars and suggests the influence of genetic mechanisms in grain yield formation under optimum conditions. In line with this, Karamanos et al. (2012) reported that grain yield is affected by various environmental conditions (e.g., water and nutrient availability in soil) and by the interaction of these conditions with the plant's genetic makeup.

Interaction nitrogen × variety on grain yield

The interaction between nitrogen and variety on grain yield (GY) was significant during both seasons (Table 3). In the 2016/2017 season, the highest grain yield was obtained at the interaction of 200 kg N ha^{-1} × Reyna-28 (3867 kg ha^{-1}), whereas the least interactive effect on GY was observed at 0 kg N ha^{-1} × El-Kodaraoua (404 kg ha^{-1}). In the 2017/2018 dry season, the results showed the best combination of the varieties Reyna-28 and Sokoll/3/ with 200 kg N ha^{-1}, producing 3566 and 3338 kg ha^{-1} of GY, respectively. These results indicate that for a good response of grain yield to nitrogen fertilizer, the choice of variety is crucial, as earlier reported by Woyema et al. (2012). A well-selected combination of wheat cultivar with an optimal nitrogen application is of great importance in yield formation.

Agronomic efficiency as affected by nitrogen levels (kg grain kg^{-1} N)

The analysis of agronomic efficiency (AE) revealed that, among the nitrogen levels, supplying wheat plants with 100 kg N ha^{-1} produced the maximum grain yield per unit increase in nitrogen in both dry seasons (Table 4). In the 2016/2017 season, the greatest AE (21.89 kg grain per kg N) was achieved at 100 kg N ha^{-1}, followed by 150 kg N ha^{-1} with 17.37 kg grain per kg N, whereas the lowest AE (12.55 kg grain per kg N) was observed at the highest nitrogen level, that is, 200 kg N ha^{-1}. The same trend was observed during the 2017/2018 season, showing the maximum AE at 100 kg N ha^{-1}, while the minimum AE was observed at 200 kg N ha^{-1}. This is consistent with the findings of Nemat et al. (2013), who reported that AE tends to be low at high nitrogen levels.

Agronomic efficiency (kg grain kg^{-1} N) as affected by wheat varieties

In Table 4, the results for the 2016/2017 dry season showed that the maximum Agronomic Efficiency (AE)

Table 4. Agronomy Efficiency (kg grain kg^{-1} N) of applied Nitrogen levels and wheat varieties in 2016-2017 and 2017-2018 at Djirataoua.

Nitrogen (kg N ha^{-1})	AE		Variety	AE	
	2016/2017	2017/2018		2016/2017	2017/2018
100	21.89	8.93	Local variety	13.67	6.48
150	17.37	6.92	Sokoll/3/	19.53	10.89
200	12.55	6.29	Norman	16.55	6.35
			Reyna-28	19.33	5.79

Table 5. Grain Yield Response Index, GYRI (kg grain kg^{-1} N) and Grain Yield at zero level of Nitrogen, GY_{0N} ($kg.ha^{-1}$) of wheat varieties in 2016/2017 and 2017/2018 dry seasons at Djirataoua.

Variety	GYRI		GY_{0N}	
	2016-2017	2017-2018	2016-2017	2017-2018
El-Kodaraoua	8.94	3.97	404	1171
Sokoll/3/	13.92	9.66	637	1406
Norman	11.96	5.09	551	988
Reyna-28	15.37	6.42	793	2281
Average	*12.55*	*6.28*	*596.25*	*1461.5*

was observed in varieties Sokoll/3/ (19.53 kg grain per kg N) and Reyna-28 (19.33 kg grain per kg N). This implies that for every increase of one unit of nitrogen, these varieties enhanced grain yield by 19.53 and 19.33 kg, respectively. The lowest AE (13.67 kg grain per kg N) was observed in the local variety El-Kodaraoua, indicating that it produced the lowest grain yield per unit of nitrogen supply.

In the 2017/2018 season, the results confirmed the best efficiency of variety Sokoll/3/ in utilizing nitrogen, followed by variety Reyna-28, while the local cultivar El-Kodaraoua and the variety Norman remained less efficient in nitrogen utilization. To produce 1000 kg of wheat grain, Sokoll/3/ needed 65.74 kg of nitrogen, while El-Kodaraoua, Norman, and Reyna-28 required 99.25, 87.33, and 79.61 kg of nitrogen, respectively. This suggests that cultivar choice is crucial for the economic compensation of each kilogram of nitrogen applied. The lowest AE in the local varieties indicates that these cultivars lack physiological and genetic mechanisms to better utilize the applied nitrogen.

Grain yield response index (GYRI) in kg grain kg^{-1} N

The GYRI of El-Kodaraoua (local check), Sokoll/3/, Norman, and Reyna-28 in the 2016/2017 season were 8.94, 13.92, 11.96, and 15.37 kg grains per kg of nitrogen, respectively (Table 5). On the other hand, the grain yield at 0 kg N ha^{-1} (GY0N) for these varieties was 404, 637, 551, and 793 kg ha^{-1}, respectively (Table 5). The average GYRI for the four varieties was 12.55 kg grain per kg of nitrogen, and the average mean value of GY0N was 596.25 kg ha^{-1}. Consequently, the varieties El-Kodaraoua and Norman belonged to the NENR (neither efficient nor responsive) group because both GY0N and GYRI for these varieties were lower than the averages (Figure 1). Sokoll/3/ and Reyna-28 belonged to the ER (efficient and responsive) group because both GY0N and GYRI for these varieties were higher than the averages (Figure 1).

In the 2017/2018 dry season, the average GYRI for the four varieties was 6.28 kg grain per kg of nitrogen, and the average mean value of GY0N was 1461.5 kg ha^{-1} (Table 5). The results indicated that El-Kodaraoua and Norman belonged to the NENR group because both GY at zero levels of nitrogen and GYRI for these varieties were lower than the averages (Figure 2). Sokoll/3/ belonged to the NER (not efficient but responsive) group, demonstrating its higher GYRI than the average but lower GY at zero nitrogen than the average of varieties. Reyna-28 belonged to the ER group because both GY0N and GYRI for this variety were higher than the averages (Figure 2).

These results suggest that significant differences exist among wheat cultivars in absorbing and utilizing nitrogen from deficient soils. Similar findings were reported by Nemat et al. (2013), who noted significant differences in GYRI between different wheat varieties. As described by Van Ginkel et al. (2001), under high nitrogen input, elevated uptake efficiency is a desirable trait, whereas when farmers grow wheat under low-input conditions, the development of cultivars with high utilization efficiency of nitrogen is considered to be more desirable.

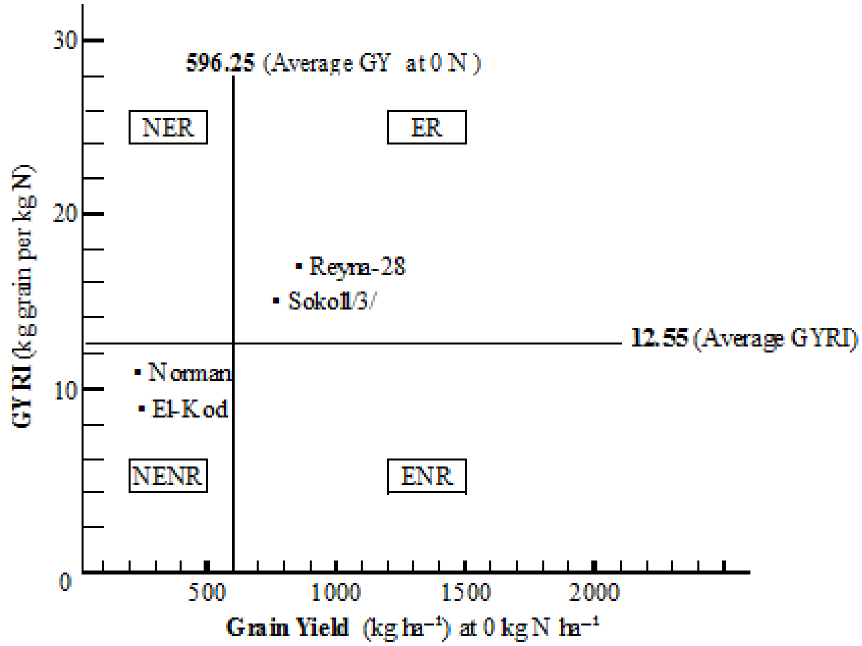

Figure 1. Grain yield response index (GYRI) of wheat varieties in 2016/2017 at Djirataoua. ER, Efficient and responsive; ENR, Efficient but Not responsive; NER, Not efficient but responsive; and NENR, Neither efficient nor responsive.

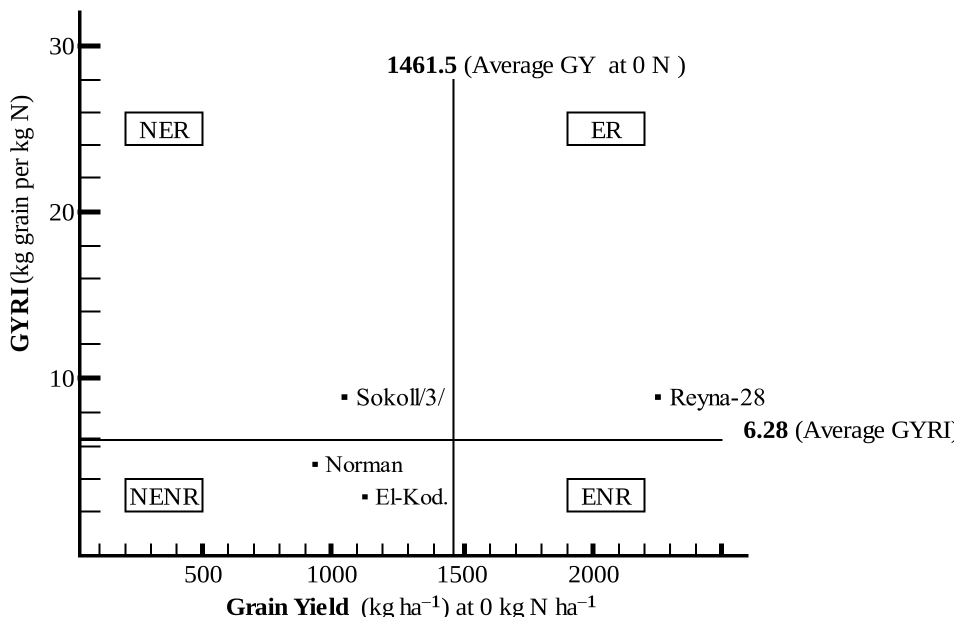

Figure 2. Grain yield response index (GYRI) of wheat varieties in 2017/2018 at Djirataoua. ER, Efficient and responsive; ENR, Efficient but not responsive; NER, Not efficient but responsive; and NENR, Neither efficient nor responsive.

Conclusion

The results of this study revealed a differential response among the studied wheat varieties in terms of grain yield. Grain yield increased with higher nitrogen levels up to 150 kg N ha^{-1}, beyond which there was no significant increase. Varieties Reyna-28 and Sokoll/3/ recorded higher grain yields. The application of 150 kg N ha^{-1} with

Sokoll/3/ and Reyna-28 was identified as the best combination for grain production. Agronomic efficiency was highest with the application of 100 kg N ha^{-1}, with variety Sokoll/3/ demonstrating the highest agronomic efficiency, showcasing its superior nitrogen use efficiency.

Referring to the analysis of the grain yield response index, the results showed that varieties Reyna-28 and Sokoll/3/ were highly responsive to nitrogen. Reyna-28 was identified as the most efficient variety, indicating its potential for producing high grain yields with low nitrogen supply. In conclusion, this study suggests that wheat production should consider the responsiveness of a wheat cultivar to applied fertilizer. Therefore, farmers in this area are recommended to apply 150 kg N ha^{-1} using variety Reyna-28 for efficient wheat production.

CONFLIT OF INTERESTS

The authors have not declared any conflict of interests.

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