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Response of Soft Wheat (*Triticum aestivum* L.) to Slow-Release Nitrogen Fertilizers in a Semi-Arid Rainfed Mediterranean Climate Area of Morocco

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ABSTRACT

Reasoned fertilization is an essential element of the agroecological approach, which aims first and foremost to improve soil and plant growth. The objective was to examine how slow-release nitrogen fertilizer will perform on the wheat productivity compared to conventional quick-release nitrogen fertilizers. A slow-release nitrogen cover fertilizer Duramon (24% N) was applied to soft wheat and compared to conventional nitrogen fertilizers as well as the local farmer practices. A randomized complete blocks design was adopted with four replications and four sites and repeated during three cropping seasons. Stand density, plant canopy height, tillers/plant, spikes/plant, biological yield, grain yield and harvest index were evaluated. Compared with conventional quick-release nitrogen fertilizers, the slow-release nitrogen significantly ($P \leq 0.05$) improved tillering, spikes/plant, canopy height, biological yield, grain yield and harvest index. It achieved an average total biomass and grain yields of 3220 kg DM/ha and 978 kg/ha, respectively. The average gains for total biomass and grain yields were 14% and 21%, respectively. However, when compared with the local farmers' practices, the gains obtained were significantly higher, with 123% and 175% for the slow-release N fertilizer and 95% and 128% for the conventional quick-release N fertilizer, respectively. The harvest index was improved by N application, rising from 25% in local controls up to 30% for slow-release N fertilizers. In conclusion, compared with conventional quick-release nitrogen fertilizers and local practices, the use of slow-release fertilizers with less units of nitrogen applied significantly improved spikes number, biological and grain yields and harvest index, even in dry years.

Keywords: conventional N fertilizers, N management, productivity, rainfed agriculture, slow-release N fertilizer, Mediterranean, semi-arid area, climate change.

INTRODUCTION

Water stress created either by a lack or rainfall irregularities, or by a low water storage capacity in the soil affects fertilizer management, particularly nitrogenous cover fertilizers and consequently impacts cereal productivity in arid and semi-arid rainfed zones (Quiza et al., 2010). The adaptation mechanisms to water stress range from morphological changes to physiological adaptations such as water use efficiency (WUE) (Baum et al. 2007). The important role of nitrogen in physiological adaptation has been reported by several investigators. These include increased chlorophyll content (Bousba et al., 2009), osmotic adjustment through cellular accumulation of amino acids (proline), sugars, ions or other compatible solutes ($K+$) (Nouri, 2002, Cai et al., 2007) and proteins (Chen and Murata, 2002; Schulze et al., 2005). Agronomic water use efficiency (WUE) is defined by the ratio of grain yield to water used during crop growth (Gilbert et al. 2011; Passioura, 2004); Under water-limited conditions, grain yield at crop production level can be expressed as a function of water used (WU), WUE and harvest index (HI) (grain yield = WU × WUE × HI) (Passioura 1977; Salekdeh et al. 2009).

Reasoned fertilization is an essential element of the agroecological approach, which aims first and foremost to improve soil and plant growth. Nutrient reasoning considers the specificities of nutrient cycles. For example, nitrogen, a mobile element in the soil in its mineral state, is reasoned over the lifetime of a crop or part of its cycle, unlike phosphorus, potassium, and magnesium, which are reasoned over a long period of time. According to the Food and Agriculture Organization of the United Nations (FAO, 2021), 38.1 MMT of N fertilizers were applied worldwide to all crops, while a third of this amount was used for wheat alone. The current challenge is to maintain or improve farmer productivity and profits with reduced agricultural inputs, primarily to grow crops more cleanly and efficiently (Barraclough et al., 2010; Hoang et al., 2010).

The research carried out to date shows that intensive agricultural production systems, which continue to be applied in high proportions throughout the world, are subject to nitrogen losses. Moreover, it is estimated that between 50% and 75% of the nitrogen brought to the field is not used by the crop and is lost through soil leaching or volatilization (Hirel et al., 2011). Globally, it is estimated that only 33% of the applied N fertilizer is recovered in harvested grain, indicating a significant waste of N and a major potential source of pollution and is therefore a major target for crop improvement (Dhillon et al., 2019). Consequently, current recommendations are to move away from the recipe-type approach of applying flat rates of N fertilizer throughout the crop cycle, to a more enlightened approach enabling a better outcome regarding wheat production, water-use efficiency, and N use efficiency (NUE) (Christie et al., 2018). The quantity, type of N fertilizer and the timing as well as methods of its application are the three key factors controlling the NUE and its effect of N fertilizer on crop yield (Che et al., 2015; Fixen et al., 2015)

In semi-arid and arid Mediterranean climatic areas, top dressing of nitrogen fertilization for rain-fed cereals cultivated is difficult to manage; thus, slow-release fertilizers (SRF) could provide a solution to simplify N management and increase rainfed cereal productivity. These types of fertilizer are compounds designed to supply the crop with nutrients, at a rate that meets its nutrient demand. Unlike quick-release fertilizers, which dissolve rapidly in the soil and supply nutrients over a relatively short period, slow-release fertilizers release nutrients over a longer period (Beig, et al., 2020; Sela, 2021). The aim of this work was to examine the effect of applying a slow-release nitrogen fertilizer, available in Morocco, on the productivity of soft wheat (Triticum aestivum L) and to compare its performance with conventional quick-release nitrogen cover fertilizers as well as farmers' local practices in the Chaouia cereal plain in Morocco.

MATERIALS AND METHODS

The agronomic trials were carried out on Calcimagnesic soils in the Chaouia cereal-growing plain in the Settat province of Morocco. The climate of this plain is semi-arid Mediterranean, with average annual rainfall of 340 mm, mild winters (minimums between 3 and 5°C) and hot summers (maximums between 35 and 41°C). The slow-release nitrogen cover fertilizer (Duramon 26) was applied to soft wheat and compared to conventional nitrogen fertilizers (ammonitrate 33.5% +Urea 46%) (Scientific Control) as well as to the local practice followed by farmers (Local Control). Duramon 26, produced by OCP-Morocco and FERTINAGRO-Spain, is a slow-release nitrogen fertilizer composed of 24% N, including 10% ammonia, 14% coated urea, 26% SO_3 and 2.2% MgO.

The management of soft wheat under the two treatments: slow-release nitrogen fertilizer and conventional fertilizer was as follows: the previous crop is a short-cycle protein pea, the variety used 'Arrihane' short-cycle and resistant to the hessian fly (*Mayetiola destructor*), the rate of fertilizer ids 30-60-60 kg/ha of N-P_2O_5-K_2O following the recommendation of the fertility map of Morocco (www.ferimap. ma), sowing during the first week of November using a combination drill at a rate of 120 kg/ha, early chemical weed control was carried out from the three-leaf stage of wheat followed by the application of 33.5 and 30 kg N/ha and at the tillering stage and 30 and 46 kg N/ha at the elongation- heading stage, for the slow-release fertilizer and rapid release N fertilizers, respectively, giving therefore a total of 109.5 kg N/ha applied for the conventional fertilizers and 90 kg N/ha for the slow-release fertilizer. Disease and insect control was carried out at the heading stage.

As far as farmers' local practices (local control) are concerned, the previous crop is wheat, the variety used is 'Arrihane', the base fertilizer dose is 20-40-40 kg N-P_2O_5-K_2O, sowing carried out after the first significant rains with a dose of 180 kg/ha. Weed control was carried, in a rainy year (2020-2022), only at the late tillering-early heading stages, with the application of 20 kg N/ha of cover fertilizer in the form of ammonium nitrate. No disease or insect treatments were applied. The total amounts of N received by each treatment are presented in Table 1:

The trials were set up as randomized complete blocks with four replications at four farmers' sites and monitored over a period of three cropping seasons: 2019-2020; 2020-2021 and 2021-2022. At the level of each elementary plot (experimental unit), 5 sub-plots of 1 m² each were randomly sampled to collect the following agronomic observations: stand density, plant canopy height, average number of tillers/plant, number of ears per plant, biological yield (straw + grain), grain yield and harvest index (grain yield/biological yield). The data collected were entered and organized, then analyzed using the multi-site, multi-year, two-factor (block x treatments) analysis of variance method (SAS Institute, 2011) and the smallest significant difference (LSD (5%) was used for the means comparison.

RESULTS AND DISCUSSION

Recap of climatic conditions

All four sites experienced the same climatic trends over the three cropping-years, namely 2019–2020, 2020–2021 and 2021–2022. The first cropping season (2019–2020) was characterized by low rainfall 217 mm/year accompanied by high minimum and maximum temperatures. The following cropping season (2020–2021) was fairly rainy, with a fairly good distribution despite the late arrival of the first rains and their early cessation in April. The amount of rain received was 362 mm/year, with a fairly warm January. In contrast, the third cropping season (2021–2022) was characterized by a severe water deficit throughout the season, only 175 mm/year received accompanied by fairly high temperatures, particularly in January and February. The late arrival of rains in March during this last cropping season saved somewhat the cropping year by producing some total dry matter by small grain cereals. These climatic contrasts had remarkable effects on wheat crop behavior and on its biomass and grain productivity, as will be presented and discussed in the following section.

Effect of N top dressing sources

Stand density, tillering, number of ears and canopy height

Compared with conventional quick-release nitrogen fertilizers (ammonium nitrate + urea), the application of slow-release cover nitrogen to soft wheat significantly ($P \leq 0.05$) improved tillering, number of spikes and canopy height. The local control, which applied insufficient quantities of nitrogen at the tillering stage, had significantly ($P \leq 0.05$) fewer tillers/plant and spikes/plant and a lower canopy height (Table 2).

Table 1. Amount of nitrogen applied to soft wheat for each treatment

Treatments	Quantity of N applied at sowing (Kg N/ha)	Quantity of N applied at tillering (Kg N/ha)	Quantity of N applied at heading (Kg N/ha)	Total amount of N applied (Kg N/ha)
Ammonitrate 33.5% + Urea 46%	30	33.5	46	109.5
Duramon 26 + Duramon 26	30	30	30	90
Local control (local practice)	20	20	0	40

Table 2. Response of stand density, number of tillers/plant, number of spikes/plant and height of soft wheat canopy to the application of two forms of top-dressing nitrogen fertilizers under rainfed agroclimatic conditions of Chaouia plains, Morocco

Treatments	Stand density* (plants/m²)	Tillers/plant*	Spikes/plant*	Canopy height (cm)*
Ammonitrate 33.5% + Urea 46%	262.8^a	2.31^b	1.11^b	55.9^b
Duramon 26 + Duramon 26	261.4^a	3.00^a	1.51^a	63.0^a
Local control (local practice)	275.9^a	1.10^c	0.72^c	40.8^c
LSD (5%)	152	0.32	0.17	3.2

Note: * Values followed by different are statistically different ($p \leq 0.05$).

Biological yield, grain yield and harvest index

Top dressing application of slow-release nitrogen significantly ($p \leq 0.05$) improved total biomass production, compared with top dressing conventional rapid release nitrogen. However, grain yield was not remarkably improved. Indeed, the slow-release nitrogen fertilizer achieved an average total biomass (straw + grain) and grain yields of 3220 kg DM/ha and 978 kg/ha, respectively, resulting in respective gains of 14% and 21%, compared with conventional nitrogen fertilizers. However, when compared with the local control, which achieved the lowest biomass (1447 kg DM/ha) and grain (356 kg/ha) yields, the gains obtained were greater, with 123% and 175% for the slow-release fertilizer and 95% and 128% for the conventional quick-release nitrogen fertilizer, respectively. The harvest index was remarkably ($p \leq 0.05$) improved by cover nitrogen, rising from 25% in local controls to 29% for fast-release fertilizers and 30% for slow-release nitrogen fertilizers (Table 3).

N top dressing sources by Cropping seasons interactions

Stand density, tillering, number of ears and canopy height

Stand density, tillering and number of spikes/plant, as well as height of soft wheat fertilized with both types of nitrogen cover fertilizer, varied significantly ($P \leq 0.05$) with cropping seasons. The highest values for these variables were obtained during the favorable cropping season (2020–2021) with, respectively, 251.9 plants/m², 2.7 tillers/plant, 1.7 ears/plant and 57.3 cm. The lowest values were observed for the driest cropping season (2021-2022), with only: 121 plants/m², 1.1 tillers/plant, 0 ears/plant and 26 cm, respectively (Table 4). Stand density was similar for all treatments across the three cropping seasons, while the other variables were significantly ($P \leq 0.05$) improved by Duramon even in dry years. The local control, which applies only small amounts of nitrogen cover fertilizer, recorded the lowest values in all three cropping seasons (Table 4).

Biological yield, grain yield and harvest index

The highest average yields ($P \leq 0.05$) were obtained during the wet cropping season with 2457 kg DM/ha for biological yield, 864 kg/ha for grain yield and an average harvest index of 35%. The dry cropping season (2019–202) had average values of 2221 kg DM/ha, 582 kg/ha and 26%, respectively. The very dry growing season (2021–2022) achieved the lowest biomass (941 kg DM/ha) and grain (163 kg/ha) yields as well as the lowest harvest index (17%) (Table 5). The average harvest index varied with the cropping season, with 35% for the rainy cropping season (normal-2020-2021), 26% for the dry cropping season (2019–2020) and 17% for the very dry cropping season (2021–2022) (Table 5).

Biological and grain yields were significantly improved ($p \leq 0.05$) by the slow-release nitrogen fertilizer in both wet and dry years. Conventional quick release nitrogen fertilizers occupied the second place, well ahead of the local control. The respective gains achieved by Duramon over conventional quick release nitrogen fertilizer over the three consecutive years were 16%; 16% and 5% for biomass yields and 25%; 20% and 7% for grain yields. Compared with the local control, the respective average gains achieved by Duramon slow-release N fertilizer and conventional quick release N fertilizers also varied with the seasons, with respectively: 149% and 114% for the biomass yields and 213% and 150% for the grain yields during the first 2019–2020 season, which was dry (217 mm/year). During the second campaign, which was rainy (362 mm/year), these gains were 117% and 88% for the biomass yields and 166% and 121% the grain yields, respectively. During the third season, which was very dry (175 mm/year), these gains were 85% and 76% for the

Table 3. Response of biological and grain yields and harvest index of soft wheat to the application of two forms of top-dressing nitrogen sources under rainfed agroclimatic conditions of Chaouia plains Morocco

Treatments	Biological yield* (kg DM/ha)	Grain yield* (kg/ha)	Harvest index* (%)
Ammonitrate 33.5% + Urea 46%	2824[b]	811[a]	29[a]
Duramon 26 + Duramon 26	3220[a]	978[a]	30[a]
Local control (local practice)	1447[c]	356[b]	25[b]
LSD (5%)	186	143	1.1

Note: * Values followed by different are statistically different ($p \leq 0.05$).

biomass and 112% and 98% for the grain yields (Table 5). The crop year × quick release nitrogen fertilizer type interaction was highly significant for the harvest index. Indeed, it improved from 30% to 37% in normal years, from 22% to 28% in dry years and only from 16% to 18% in very dry years (Table 5). The application of quick release nitrogen fertilizer in adequate quantities and at

Table 4. Response of stand density, number of tillers/plant, number of spikes/plant and height of soft wheat canopy to the application of two forms of top-dressing nitrogen fertilizers during three cropping seasons under rainfed agroclimatic conditions of Chaouia plains, Morocco

Cropping seasons	Treatments	Stand density* (plants/m²)	Tillers/plant*	Spikes/plant*	Canopy height* (cm)
2019–2020	Ammonitrate + Urea	228.9[a]	1.13[b]	0.81[b]	37.6[b]
	Duramon + Duramon	222.5[a]	1.43[a]	1.12[a]	43.2[a]
	Local control	229.6[a]	0.44[c]	0.42[c]	28.5[c]
	LSD (5%)	28.2	0.13	0.13	2.7
	Means	227.0[b]	1.00[b]	0.78[b]	35.8[b]
2020–2021	Ammonitrate + Urea	241.9[a]	2.92[b]	1.74[b]	60.2[b]
	Duramon + Duramon	245.8[a]	3.63[a]	2.38[a]	65.4[a]
	Local control	268.2[a]	1.70[c]	1.13[c]	46.4[c]
	LSD (5%)	17.1	0.31	0.22	2.1
	Means	251.9[a]	2.75[a]	1.75[a]	57.3[a]
2021–2022	Ammonitrate + Urea	120.5[a]	1.22[b]	0.11[a]	27.9[b]
	Duramon + Duramon	119.8[a]	1.64[a]	0.28[a]	33.2[a]
	Local control	122.9[a]	0.42[c]	0.04[a]	16.8[c]
	LSD (5%)	44.2	0.16	0.32	4.8
	Means	121.1[b]	1.09[b]	0.14[c]	25.9[c]
	LSD(5%)	10.3	0.78	0.30	4.3

Note: * Values followed by different are statistically different (p≤0.05).

Table 5. Response of biological and grain yields and harvest index of soft wheat to the application of two forms of top-dressing nitrogen fertilizers during three cropping seasons under rainfed agroclimatic conditions of Chaouia plains Morocco

Cropping seasons	Treatments	Biological yield* (Kg DM/ha)	Grain yield* (Kg/ha)	Harvest index* (%)
2019–2020	Ammonitrate + Urea	2534[b]	659[a]	26.2[b]
	Duramon + Duramon	2946[a]	824[a]	28.1[a]
	Local control	1182[c]	264[b]	22.2[c]
	LSD (5%)	180	117	0.8
	Means	2221[b]	582[b]	26.5[b]
2020–2021	Ammonitrate + Urea	2742[b]	976[b]	36.3[a]
	Duramon + Duramon	3168[a]	1174[a]	37.4[a]
	Local control	1462[c]	442[c]	30.1[b]
	LSD (5%)	207	87	0.9
	Means	2457[a]	864[a]	34.6[a]
2021–2022	Ammonitrate + Urea	1079[a]	189[a]	18.1[a]
	Duramon + Duramon	1132[a]	202[a]	18.4[a]
	Local control	612[b]	96[b]	16.1[b]
	LSD (5%)	21	33	0.4
	Means	941[c]	163[c]	17.5[c]
	LSD (5%)	113	98	0.78

Note: * Values followed by different are statistically different (p≤0.05).

the critical stage of wheat development (tillering and early heading) in the rainfed semi-arid zone of Chaouia, Morocco, had a significant impact on growth, yield and harvest index. These results confirm the importance of nitrogen fertilization in improving cereal productivity, as reported by several investigators (Guarda et al., 2004, Alam et al., 2007). As farmers in rainfed areas have difficulty managing nitrogen fertilizer under uncertain climatic conditions, they prefer to reduce the risk by applying small quantities, especially as the nitrogen in fertilizers (ammonitrate and urea) is quickly released, which reduces the efficiency of use of this element and could aggravate water stress in the case of drought.

The gains achieved in terms of total biomass and grain yield by the slow-release nitrogen fertilizer compared with conventional quick-release fertilizers, even in dry years, indicate the possibility of improving water-use efficiency (WUE) and nitrogen-use efficiency (NUE) while reducing the total amount of N applied and fractioning its application during the growth cycle of the wheat crop. These results also indicate that the gains achieved in normal climatic years and in moderately dry years are higher than those obtained in severely dry years. These gains are higher than those obtained with conventional fertilizers, which led to an early senescence of the wheat crop.

Modeling analyses highlighted the intrinsically high degree of seasonal variability in wheat yield, water use efficiency, nitrogen use efficiency, depending on soil type, quick release nitrogen fertilizer application and type, rainfall amount and rainfall distribution (Asseng et al., 2001). Clay soil tended to be more productive in terms of grain yield, WUE and NUE in the high rainfall (450 mm/year) and medium rainfall (350 mm/year) Mediterranean zones, but less productive in most seasons in the low rainfall zone (250 mm/year) (Asseng et al., 2001). According to Cui et al., 2006, optimizing N use for wheat by using slow-release N fertilizers significantly reduced N losses to the environment without compromising crop yields.

CONCLUSIONS

In conclusion, the application of quick release nitrogen fertilizers has a significant impact on the growth, yield, and harvest index of soft wheat during all cropping seasons. Compared with conventional quick-release nitrogen fertilizers, ammonium nitrate and urea, the use of slow-release fertilizers with fewer units of nitrogen applied, such as Duramon 26, significantly improved tillering, ear number, canopy height, biological and grain yields and harvest index, even in dry years. The increase in biomass and grain production, as well as the improvement in harvest index, indicates the improvement in water and nitrogen use efficiency under arid rainfed and arid seeded Mediterranean conditions. The availability of this type of slow-release nitrogen fertilizer will help farmers to manage nitrogen top dressing fertilization in the areas subject to climatic hazards, through its fractioning into three applications along the cereal cycle, in addition to reducing the quantity to be applied, which will be economical for growers and beneficial for the environment.

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