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Combining yield gap and efficiency analysis to analyze farmers' fields network: a case study on nitrogen in durum wheat in Tunisia

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1 Introduction

In most Mediterranean regions, durum wheat yield is variable with time and location, depending on several factors, primarily water and nitrogen supply (Boussen *et al.,* 2005). Nitrogen (N) is one of the most important nutrients applied as a fertilizer and responsible to a great extent for the large yields obtained from high input agriculture (Latiri, 1998). However, the increased use of N fertilizer can affect farmers' margins, causes excessive losses to the environment and make agriculture dependent of non-renewable energy. The simultaneous increase in both yield and N-efficiency is at the core of eco-efficient agriculture which targets efficient and sustainable use of resources in agricultural production and land management (Keating *et al.*, 2010). It adds to the concept of ecological intensification (Cassman, 1999), the hypothesis of eco-efficiency frontiers that are determined by the genetic nature or by the agrobiodiversity of the cropping systems.
This study aims to analyze the efficiency of nitrogen supply on durum wheat and its drivers in different regions in Tunisia and try to identify eco-efficiency frontiers, associated with constrasting rotation sequences. We addressed the following question: Can higher yields and greater N-efficiency be expected in wheat-based cropping systems by diversifying rotation sequences?

2 Materials and Methods

Assessing the prospects for eco-efficiency on durum wheat production in Tunisia requires compiling and analyzing available data on crop performance and resource inputs as they are currently managed by farmers. Farm surveys were conducted on a sample of 576 farmers' fields which are representative of the diversity of farmers' practices in four grain-producing regions: 182 in Jendouba, 62 in Siliana, 198 in Kairouan and 134 in the Lebna catchment of the Cap Bon. Among these fields 310 were irrigated and 266 were rainfed. The resulting database contains information on wheat yields, N inputs, climatic parameters, previous crop in rotation sequences and other information about the crop management system.
The analysis of yield variability and N-efficiency is based on the concept of efficiency frontier (Keating *et al.,*2010; Carberry *et al.,* 2013). This approach involved analyzing durum wheat responses to N supply over a boundary curve which represents the maximum achievable yield when the input (here N) is the only limiting factor, using the following model (Fermont *et al.,* 2009):

$$\mathbf{Y = Ymax / (1 + K * Exp(-R * X))}$$

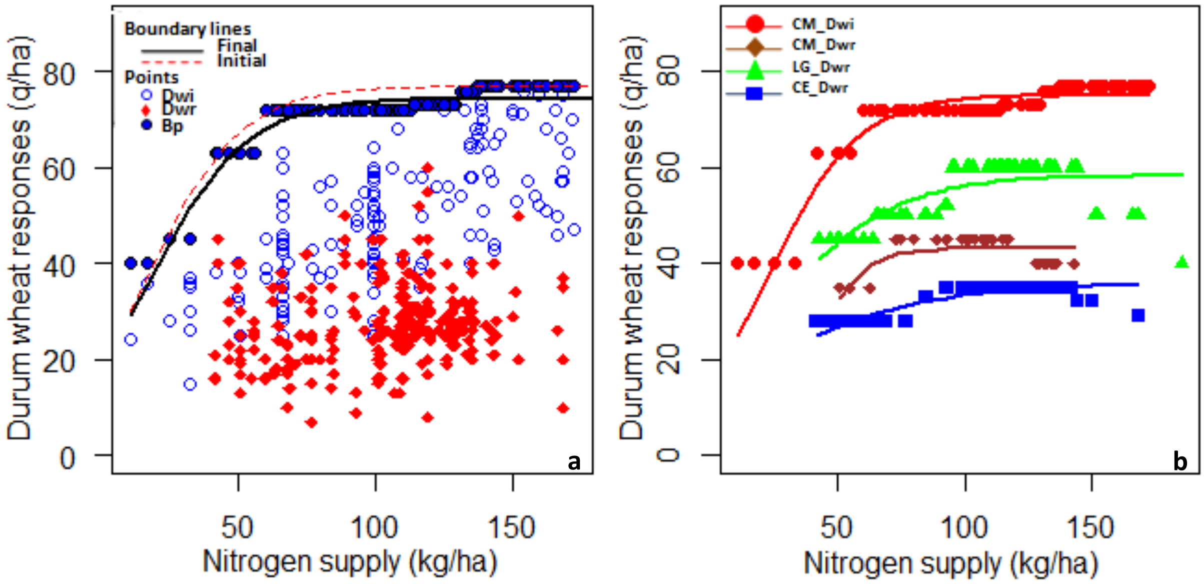
Where Ymax is the maximum level observed in the target variable (durum yield), X is the independent variable (nitrogen), and K and R, are two constants obtained by minimizing the root mean squared error (RMSE).

In order to sort the points that were used to define the boundary curves, we chose a window of fixed size, on the x-axis, and we calculated the maximum yield for each value of the independent variable (N). Then, we formed pairs of points, within the window, where each value of yield was replaced by maximum yield (X, Ymax). In this way, we created a new data set, to which a global boundary curve was first fitted for all the fields together. Then, distinct curves were fitted and tested according to rotation type. The different crop rotations included: (i) vegetable crops-wheat rotation (CM-Dw), (ii) legumes-wheat rotation (LG-Dw), and (iii) cereal (including wheat)-wheat rotation (CE-Dw).

3 Results and discussion

The performance of durum wheat grown in the four sites is benchmarked against a boundary curve that represents achievable yield (boundary points) when only nitrogen is limiting yield (Fig. 1a). The observed achievable yield (Ymax) was 75 q/ha. However, a large variability was observed in yield and yield gap. This variability was, in part, explained by water supply and its distribution. As indicated by the difference in boundary curve between irrigated and rainfed wheat (Fig. 1b). Other biotic and abiotic factors may also partly explain yield gap, such as poor soil quality, or lack of crop protection.
The effect of the preceding crop was a key factor in wheat yield and nitrogen efficiency relationship. Boundary curves of

wheat response to nitrogen supply were found significantly different according to rotation type (Fig. 1b). The highest Ymax (75 q/ha) was found for irrigated wheat following vegetables crops (CM_Dwi). In addition to water supply, the significantly higher performance and N-efficiency of this rotation compared to the other can be explained by fertlization and weeding practices on the vegetables, which altogether resulted in favorable growing conditions for wheat. By contrast, the lowest achievable yield (37q/ha) was found for rainfed wheat in cereal-wheat rotation (CE_Dwr), revealing the poor N-efficiency of rotation sequences based on cereals only. At intermediate positions were the rainfed wheat in rotation with vegetable crops (CM_Dwr, 44q/ha) and legumes (LG_Dwr, 58q/ha), illustrating the range of achievable durum wheat yields depending on the preceding crop. Apparently, legumes had higher fertilizing effects than did vegetable crop, probably due to greater soil N enrichment through legume N-fixing processes than N-credit from vegetables. Furthermore, the large gap between irrigated and rainfed wheat in wheat-vegetable crop rotations suggested important interactions between the effects of water and N supply on durum wheat performances.



Initial	Estimated	Std. Error	t value	Pr(>|t|)
Ymax= 77	74.444404	0.152712	487.48	<2e-16
K= 3	2.881828	0.210332	13.70	<2e-16
R= 0.06	0.056817	0.001786	31.81	<2e-16

Parameters	CM_Dwi	CM_Dwr	LG_Dwr	CE_Dwr
Ymax	75.120967	43.1738	58.36679	35.86087
K	3.805370	79.4774	2.67589	1.58634
R	0.058005	0.1077	0.04234	0.03087

Fig. 1. The relationship between nitrogen supply and durum wheat perfomances in irrigated (Dwi) and rainfed (Dwr) system compared to a boudary line representing maximum yields or boundary points (Bp)(a) and eco-efficiency frontier with each type of rotation: CM_Dwi: irrigated wheat after crop vegetable, CM_Dwr: rainfed wheat after crop vegetable, CE_Dwr: rainfed wheat after cereals, LG_Dwr: rainfed wheat after legumes (b)

4 Conclusions

In this study, grain yield responses of durum wheat to nitrogen supply, in a Mediterranean environment was used as a framework in the diagnosis of yield gap and nitrogen efficiency frontiers. In addition to the water supply and distribution, potential yields (Ymax) and yield gap can be explained by crop rotations. This analysis validate the hypothesis of higher eco-efficiency frontier determined by diversified crop rotations compared to cereal-based rotations and allow to identify strategies to reduce yield and N efficiency gaps.

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