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Rafael J. López-Bellido Garrido, Luis López-Bellido. Effects of crop rotation and nitrogen fertilization on soil nitrate and wheat yield under rainfed Mediterranean conditions. *Agronomie*, 2001, 21 (6-7), pp.509-516. 10.1051/agro:2001140 . hal-00886136

HAL Id: hal-00886136

<https://hal.science/hal-00886136v1>

Submitted on 11 May 2020

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Effects of crop rotation and nitrogen fertilization on soil nitrate and wheat yield under rainfed Mediterranean conditions

Rafael J. LÓPEZ-BELLIDO GARRIDO^a, Luis LÓPEZ-BELLIDO^{b*}

^a Departamento de Biología y Producción de los Vegetales, University of Extremadura, 06071 Badajoz, Spain

^b Departamento de Ciencias y Recursos Agrícolas y Forestales, University of Córdoba, PO Box 3048, 14080 Córdoba, Spain

(Received 28 December 2000; revised 15 May 2001; accepted 13 July 2001)

Abstract – A field study was conducted from 1988 to 1998 to determine the effects of crop rotation and N fertilizer on wheat (*Triticum aestivum* L.) yield in a rainfed Vertisol Mediterranean region. Over the last 3 years of the study, the effect of crop rotation on residual soil NO_3^- -N before sowing and after wheat harvest was also examined. Crop rotations were wheat-sunflower, wheat-chickpea, wheat-faba bean, wheat-fallow and continuous wheat, with three different N fertilizer rates: 50, 100 and 150 kg N-ha⁻¹. A split plot design with four replications was used. Differences in rainfall during the growing season had a marked effect on wheat yield. Excessive winter rainfall, of over 450 mm, prompted a decrease in yield. The wheat-faba bean rotation was the most effective of all rotations tested: wheat yields were more stable for all N fertilizer rates. The effect of chickpea rotation on wheat yield was clearly smaller than that of faba bean rotation, and generally similar to that of sunflower rotation. Wheat-sunflower and wheat-chickpea displayed the lowest NO_3^- -N levels. Monoculture prompted consistently lower yields than 2-y rotations, and also led to a dangerous accumulation of soil NO_3^- -N, owing to lower N use efficiency. Soil NO_3^- -N levels under wheat-faba bean and wheat-fallow rotations were similar, but in both cases lower than those recorded for wheat monoculture. N use efficiency (NUE) was greater in wheat-sunflower and wheat-faba bean rotations.

wheat / legume / crop rotation / soil nitrate / N fertilizer

Résumé – Effets de la rotation des cultures et de la fertilisation azotée sur les nitrates du sol et sur le rendement du blé dans des conditions de terrain non irrigué de la région méditerranéenne. Une étude a été réalisée de 1988 à 1998 pour déterminer les effets de la rotation des cultures et le N fertilisant sur le rendement du blé (*Triticum aestivum* L.) dans un Vertisol de terrain non irrigué de la région méditerranéenne. Au cours des trois dernières années on a également étudié l'effet de la rotation des cultures sur le NO_3^- -N résiduel du sol avant la semence et après la récolte du blé. Les rotations de cultures ont été : blé/tournesol, blé/pois-chiches, blé/fèves, blé/jachère et la monoculture de blé, avec trois doses différentes de N fertilisant 50, 100 et 150 kg N-ha⁻¹. On a utilisé une disposition sur des parcelles subdivisées à quatre répétitions. Des différences de pluie pendant la période de croissance ont eu un effet notable sur le rendement du blé. L'excès de pluie hivernale, plus de 450 mm, a entraîné une diminution du rendement. La rotation blé/fèves a été la plus effective de toutes celles que l'on a essayées. Les rendements de blé ont été les plus stables pour toutes les doses de N fertilisant. L'effet du pois-chiche sur le rendement du blé a été nettement inférieur à celui des fèves, révélant ainsi un effet généralement identique à celui exercé par le tournesol. Les rotations blé/tournesol et blé/pois-chiches ont révélé les niveaux les plus bas de NO_3^- -N. La monoculture a produit systématiquement moins de rendements que les rotations bi-annuelles, et a également

Communicated by Jean-Jacques Drevon (Montpellier, France)

* Correspondence and reprints
cr1lobel@uco.es

produit de dangereuses accumulations de NO_3^- -N dans le sol, dues à l'efficacité moindre du N. Les niveaux de NO_3^- -N des rotations blé/fèves et blé/jachère sont très semblables mais inférieures à la monoculture de blé. L'efficacité de l'utilisation du N (NUE) a été supérieure aux rotations blé/tournesol et blé/fèves.

blé / légumineuses / rotation des cultures / sol nitrate / engrais azoté

1. INTRODUCTION

Monoculture is a widespread practice in many farming systems, and is generally prompted by economic and market-related considerations. However, monoculture generates a number of agronomic and management problems. Increased weed populations, greater proliferation of pests and diseases and less efficient use of water and nutrients are among the causes of reduced yield in wheat monoculture. Many published studies highlight these drawbacks and point to the advantages and the greater efficiency of crop rotations in various situations and farming systems [4–6, 13, 18, 20, 21].

In the Mediterranean climate, the lack of water renders fallow a necessary practice on many soils. However, the role of fallow is currently the subject of some debate, in terms of its ability not only to restore soil fertility but also to store water for the following crop and eliminate weeds. In dry areas, the cereal-fallow system is less efficient as regards water and N use when the cereal is grown in rotation with other plants [8, 29]. According to Rasmussen and Collins [24], fallow generally prompts a greater loss of soil organic matter, compared with continuous cropping and even with monoculture. Moreover, the cereal-fallow system leaves half the land unused every year.

Incorporation of a legume in rotation with cereal prompts a marked increase in cereal yield compared with monoculture [3]. The increase in yield may be as much as 50%, due not only to biologically-fixed N_2 but also to other factors, including improvement of the physical characteristics of the soil, reduced incidence of pests and disease and of weed-related problems, elimination of phytotoxicity and the increased presence of growth-promoting substances [23, 27]. The amount of N_2 fixed by the legume varies widely as a function of species, location, management and other factors [9]. Residual N remaining in the soil for the next crop following symbiotic fixing by the legume also varies according to cropping and harvesting practices. Loomis and Connor [14] report that while the factors affecting N_2 fixation are well documented, little is known about the interactions between these variables and their effect on total available N. This information is of particular value in determining the amount of N supplied to the soil by legumes. Papastylianou [20] and López-Bellido et al. [16] report

that, in Mediterranean conditions, legumes have a positive effect on cereal yield.

Legume crops may have a considerable effect on a number of soil properties, reducing the C/N ratio of residue incorporated into the soil, which may substantially alter microbial activity, N transformations, nutrient availability and plant growth. According to Power [23], soils in which legumes have historically been grown tend to have a higher level of total organic matter, which improves soil quality and fertility. Use of legumes in a cropping system may lead to an improvement in soil structure through changes in organic matter content, soil microbial activity and deep root growth, which facilitates root penetration by the following cereal crop [10, 26]. Moreover, legumes break the cycle of many cereal diseases [5, 13, 26].

The move towards sustainable agriculture has prompted renewed interest in crop rotations and their effect on N use efficiency. The availability of N immobilized in legume residue for following crops varies widely, depending on a number of factors. Legume N is mineralized more slowly and used more efficiently than high rates of chemical N fertilizer. Rotations trigger changes in soil N sources, which obviously affect N use efficiency. Pierce and Rice [21], Badaruddin and Meyer [1], Stockdale et al. [28] and Yamoah et al. [30] have stressed the greater N use efficiency of rotations as compared to monoculture, highlighting the fact that this efficiency is particularly enhanced by legume rotations.

In current practice, legumes are not widely used in crop rotations when N fertilizer is available; their use is governed more by their production value than by their contribution to N_2 fixation. The farmer thus faces an awkward choice: he may opt either to increase soil fertility in the long term or to ensure greater short-term advantage by growing more profitable crops. However, changes are becoming apparent in the agricultural policies of many developed countries, prompted by structural surpluses of many food products, which have led to increasingly extensive production and the abandoning of arable land. In the search for a more rational farming system, greater importance should be attached to legumes both as a source of N and as an environmentally friendly crop.

There is limited information on the long-term effect of legumes and crop rotation for the semiarid

Mediterranean region. This study addressed the effect of crop rotation (including legumes) and N fertilizer practice on N dynamics in soil and wheat yield, as part of a long-term experiment on a rainfed Mediterranean agricultural system.

2. MATERIALS AND METHODS

Field experiments were conducted at Córdoba, in the south of Spain, on a Vertisol (Typic Haploxererts) typical of the Mediterranean region. The experiment started in the autumn of 1986. The experiment was designed as a randomized complete block with a split plot arrangement and four blocks. Main plots were crop rotation, with four different 2-yr rotations (wheat-sunflower, wheat-chickpea, wheat-faba bean, and wheat-fallow) and continuous wheat; subplots were N fertilizer rates (50, 100 and 150 kg N·ha⁻¹) applied to wheat only. Each rotation was duplicated in the reverse crop sequence to obtain data for all crops on a yearly basis. The area of each sub-subplot was 50 m² (10 × 5 m). The effect of treatments on wheat yield was studied over 11 years (1987–88 to 1997–98); soil NO₃⁻-N content for each rotation as a function of N fertilizer rates (including a subplot of 0 kg N·ha⁻¹ introduced once the experiment has started) and wheat N use efficiency for each rotation were studied over the last three years of the experiment (1995–96 to 1997–98).

Hard red spring wheat (cv. Cajeme) was planted in 18-cm wide rows in December at a seeding rate of 150 kg·ha⁻¹. Sunflower (various hybrid cultivars) was planted in 50-cm wide rows in February at a seeding rate of 5 kg·ha⁻¹. Winter chickpea (cv. FLIP-84/1SC) was planted in 35-cm wide rows in December at a seeding rate of 80 kg·ha⁻¹. Faba bean (cv. Alameda) was planted in 50-cm wide rows in November at a seeding rate of 170 kg·ha⁻¹. Wheat grain was harvested in early June using a 1.5 m-wide Nurserymaster Elite Plot Combine (30 m² per sub-subplot).

Nitrogen fertilizer was applied to wheat plots as ammonium nitrate. At all application rates, half was applied before sowing. The remaining N was applied as top dressing at the beginning of wheat tillering corresponding to stage 21 of Zadocks scale [31]. Every year wheat plots were also supplied with P fertilizer at a rate of 65 kg P₂O₅·ha⁻¹. Soil-available K was adequate.

Weeds within the growing season were controlled by means of specific herbicides, namely: diclofop methyl + tribenuron at 0.9 L a.i.·ha⁻¹ and 15 g a.i.·ha⁻¹, respectively, for wheat; and cyanazine at 2 kg a.i.·ha⁻¹ for chickpea and faba bean.

In the last 3 years of the study, soil samples were taken on all plots in autumn and summer, before wheat-sowing and after wheat-harvesting respectively, to a depth of 90 cm. Soils were analyzed for nitrate content using the Griess-Illosvay colorimetric method as modified by Barnes and Folkard [2], with a Bran & Luebbe II AutoAnalyzer. N use efficiency (NUE) was calculated as the ratio of grain yield to N supply, where N supply is the sum of soil NO₃⁻-N at sowing, mineralized N and N fertilizer. The amount of N mineralized for each site-year was estimated as the difference between preplanting and postharvest plant and soil inorganic N in control (0 kg N·ha⁻¹) [12].

Data for each parameter were subjected to analysis of variance (ANOVA), using a combined year randomized complete block design according to McIntosh [19]. Treatment means were compared using Fisher's protected least significant difference (LSD) test at $P \leq 0.05$. Least significant differences for different main effect and interaction comparisons were calculated. The Statgraphics Plus v. 7.0 software suite [17] was used for this purpose.

A regression between wheat yield and winter rainfall was analyzed. Effect of rotation was determined by comparing yield differences between rotations and monoculture according to Hesterman et al. [11]. A stability analysis was also performed in order to compare the different rotations in terms of N fertilizer rate on the basis of environmental index, defined as the average yield of all rotations in a given year, which was obtained for 50, 100 and 150 kg N·ha⁻¹ [7, 25].

3. RESULTS AND DISCUSSION

3.1. Grain yield and rainfall

From the start of this long-term experiment, in 1986, rainfall was extremely variable, with a very dry period during the middle years and heavy rainfall over the last three years (Fig. 1). Annual wheat yield over the 11 years of the experiment (Fig. 1) displays marked differences, resulting from interannual variation in rainfall during the growing season. Yield in the wettest years (1996–97 and 1997–98) was as low as in the driest years, since waterlogged conditions prevented satisfactory wheat development. Regression analysis for wheat yield and annual rainfall was highly significant ($r^2 = 0.74$). However, when rainfall over the vegetative period (November–February) was considered, the goodness of fit improved and the value of the regression coefficient increased (Fig. 2). Similar results were obtained by López-Bellido et al. [16] for the same experiment, except that data for a predominantly dry period fitted a linear

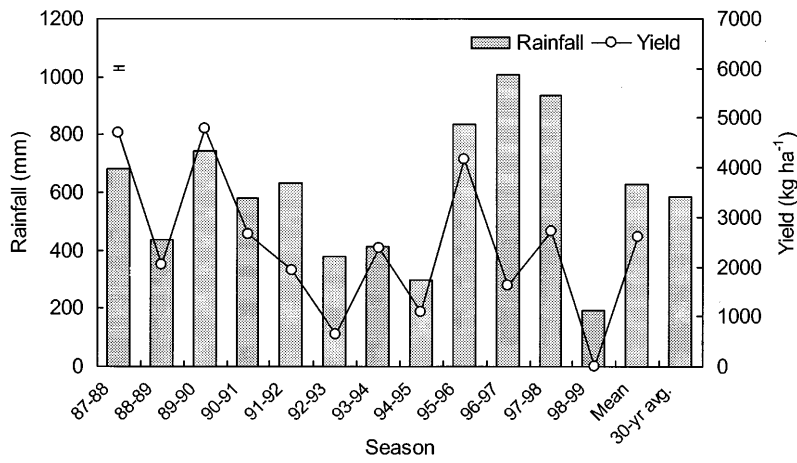


Figure 1. Annual precipitation and wheat yield of twelve seasons at Córdoba (Spain).

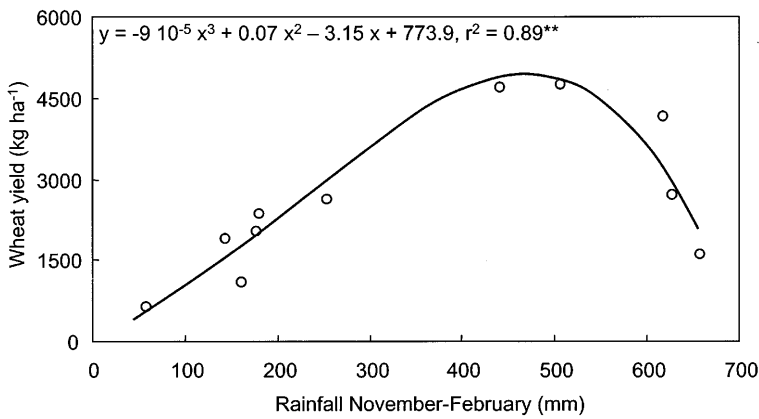


Figure 2. Relationship between wheat grain yield and November-February rainfall for a 11-y experiment at Córdoba (Spain).

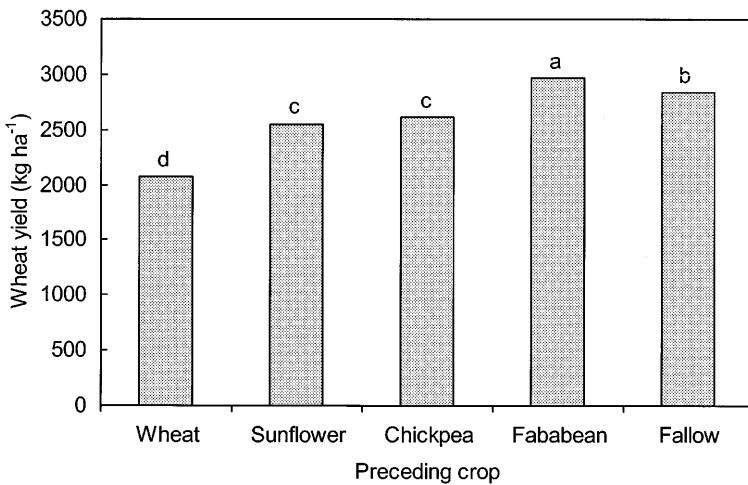


Figure 3. Influence of 2-y rotation on wheat yield in a rainfed Vertisol, southern Spain. Average 11 years (different letters indicate significant differences at $p < 0.05$ according to LSD).

regression. In the present study, which includes wetter years, the best fit was a polynomial curve, showing a decrease in yield above a given level of rainfall (roughly 450 mm) during the wheat vegetative season.

3.2. Effects of crop rotation on grain yield

Wheat yield varied significantly with crop rotation each season and for the 11 years as a whole (Fig. 3). The greatest 11-y average yields occurred with the wheat-faba bean rotation, which differed markedly from the other rotations. Considerable differences were recorded between the other rotations (wheat-fallow > wheat-chickpea = wheat-sunflower > continuous wheat).

Inter-year changes in weather patterns resulted in some deviations from the general behavior of wheat yield for the different rotations. Differences between legume species in their ability to fix atmospheric nitrogen and hence the amount of residual N that is supplied to soil have been reported to influence cereal yield [10]. The difference between faba bean and chickpea was quite clear-cut in our experiments: wheat yield was greater following a faba bean rotation than a chickpea rotation – the latter effect was even less than that of fallow. According to Heichel [9] the N_2 fixed by faba bean ($\text{kg}\cdot\text{ha}^{-1}\cdot\text{y}^{-1}$) is 3–5 times greater than that fixed by chickpea. Pilbeam et al. [22], under Mediterranean conditions, obtained 16–48 $\text{kg}\cdot\text{ha}^{-1}\cdot\text{y}^{-1}$ of chickpea-fixed N_2 , depending on the season; the amount of N removed in the grain was usually greater than the amount of atmospheric N_2 fixed.

Table I quantifies the effect of rotation, expressed as the difference (increase or decrease) in yield compared to wheat monoculture. The greatest rotation effect for the

Table I. Rotation effect of sunflower, chickpea, faba bean and fallow on wheat grain yield compared with continuous wheat for different N rates applied to wheat in a rainfed Vertisol, southern Spain. Average 11 years.

Rotation	Rotation effect ¹			Mean
	N rate ($\text{kg}\cdot\text{ha}^{-1}$)			
	50	100	150	
Wheat-sunflower	665c ²	596c	613b	625c
Wheat-chickpea	657c	645c	631b	644c
Wheat-fababean	1037a	1004a	802a	948a
Wheat-fallow	894b	849b	794a	846b

¹ Yield of wheat in the rotation-yield of wheat in monoculture.

² Within N rate and mean different letters indicate significant differences at $p < 0.05$ according to LSD.

11 years as a whole was exhibited by faba bean following fallow. Chickpea and sunflower exhibited smaller rotation effect values. Rotation effect decreased with increasing N-fertilizer rate because monoculture wheat yields increased with rising N rates. Over the first 7 years of the same experiment, López-Bellido et al. [16] found no significant difference in rotation effect for wheat-faba bean and wheat-fallow at any of the three N rates used; in the present study, absence of significant difference was found only for 150 $\text{kg N}\cdot\text{ha}^{-1}$.

Continuous wheat responded to up to 150 $\text{kg N}\cdot\text{ha}^{-1}$ and the rotations to up to 100 $\text{kg N}\cdot\text{ha}^{-1}$ (Fig. 4). Wheat yields for monoculture at the maximum N rate (150 $\text{kg N}\cdot\text{ha}^{-1}$) were lower than those obtained with rotations at the minimum N rate (50 $\text{kg N}\cdot\text{ha}^{-1}$).

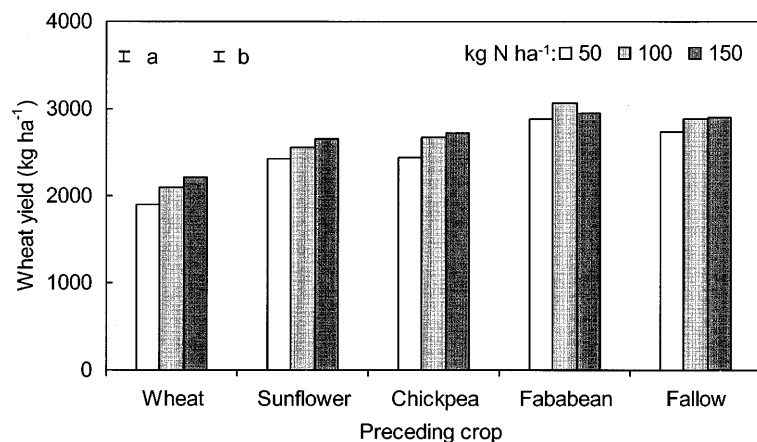


Figure 4. Effect of crop rotation and N rate on wheat grain yield in a rainfed Vertisol, Southern Spain. Average 11 years (vertical bars represent LSD, $p < 0.05$; a: within rotation; b: between rotations).

The availability of additional water accumulated by fallow under semi-arid conditions has traditionally been assumed to be a key to wheat productivity [15]. However, our results for the driest seasons reveal that fallow did not increase wheat yield relative to other rotations (rainfall ranging from 300 to 600 mm). Even in the wettest years (rainfall from 600 to 1000 mm) wheat yield was higher in the wheat-faba bean rotation than in the fallow rotation, which displayed a pattern similar to that of the other rotations.

A stability analysis was performed to evaluate interactions between rotations and environment (data not shown). Rotation stability was affected by N fertilizer rate. Differences between continuous wheat and all rotations became more marked as yield increased at all N rates. The wheat-chickpea and wheat-sunflower rotations displayed similar behavior at all N rates, a preceding chickpea crop again proving to have a small effect on wheat yield. The wheat-faba bean rotations displayed, with respect to fallow, a more marked influence on wheat yield at lower N rates (50 y 100 kg N·ha⁻¹) than at the highest rate (150 kg N·ha⁻¹). These results confirm behavior similar to that reported for the rotations studied by López-Bellido et al. [16] over a shorter period, and testify to the positive residual effect of faba bean preceding a cereal crop in Mediterranean conditions.

3.3. Soil nitrate

Crop rotations displayed significant differences with respect to NO₃⁻-N content at each N rate (Fig. 5). At 0 kg N·ha⁻¹, wheat-fallow and wheat-faba bean displayed in most cases significantly greater NO₃⁻-N content than the remaining rotations. Also, at 0 kg N·ha⁻¹ no difference was recorded between continuous wheat and the two rotations on the last three dates sampled. At other N rates, continuous wheat generally displayed greater NO₃⁻-N content, because it was fertilized annually while rotations received N-fertilizer only every two years. The low NO₃⁻-N levels recorded for the wheat-chickpea rotation again testified to the low residual N supplied by this legume, levels staying close to those of the wheat-sunflower rotation at all N rates. However, the wheat-sunflower rotation displayed in many cases the lowest NO₃⁻-N levels, marking it as an excellent complement to wheat in terms of N use, and highlighting its environment-friendly role.

3.4. Nitrogen use efficiency

N use efficiency (NUE) was considerably lower in wheat monoculture and higher in wheat-faba bean,

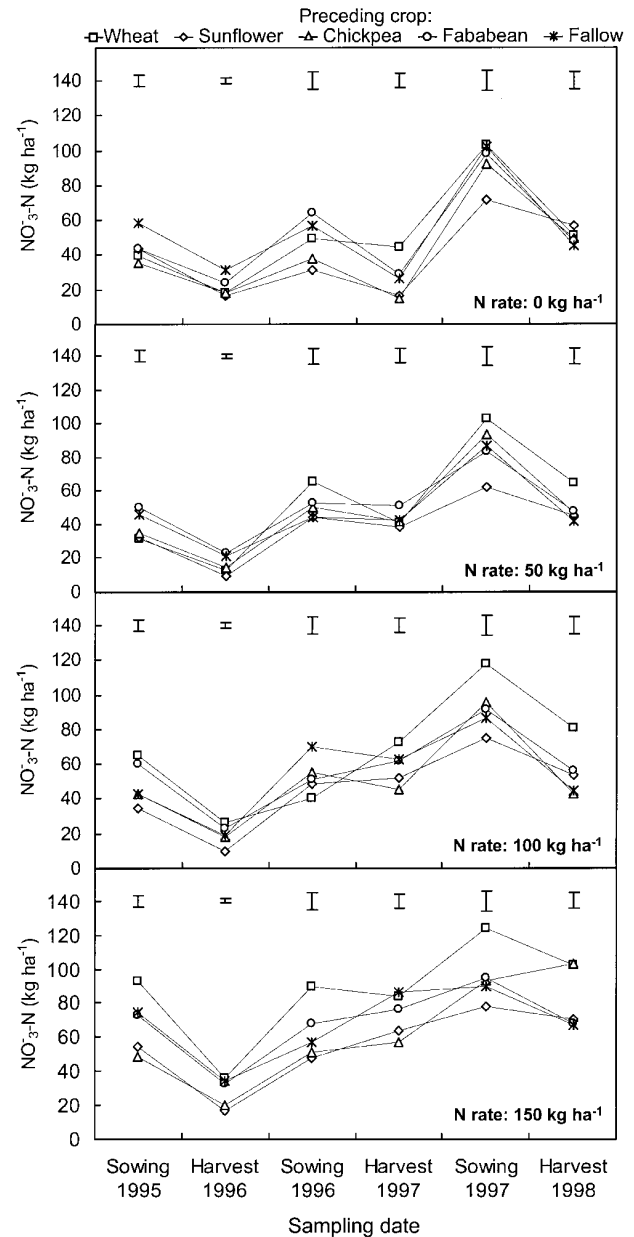


Figure 5. Effects of crop rotation according to N rate on soil NO₃⁻-N (0–90 cm) in a rainfed Vertisol, Southern Spain (vertical bars represent LSD, $p < 0.05$).

wheat-chickpea and wheat-sunflower rotations; no significant differences were recorded for these rotations over the whole of the experiment. The wheat-fallow rotation occupies an intermediate position (Fig. 6). These results agree with those reported by Pierce and Rice [21]

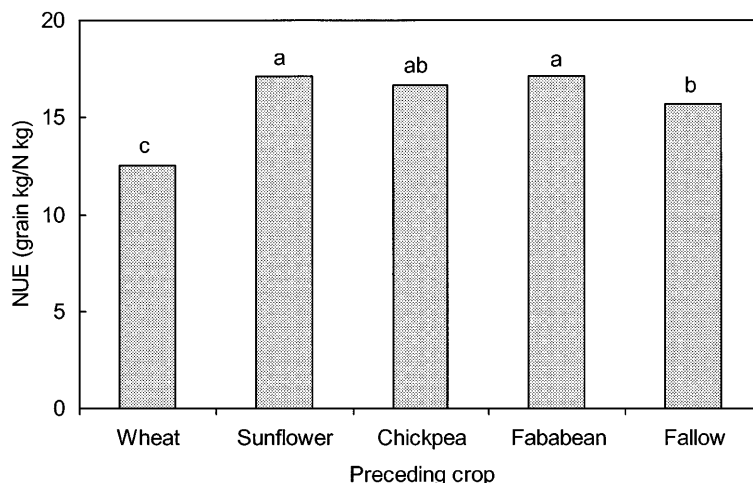


Figure 6. Influence of 2-y rotation on N use efficiency (NUE) in wheat (grain yield produced per unit of N supply). Average 3 years (different letters indicate significant differences at $p < 0.05$ according to LSD).

and by Stockdale et al. [28], who found a lower NUE value for continuous wheat. According to Badaruddin and Meyer [1], the NUE value in wheat following a legume crop is greater than that of wheat following fallow and of continuous wheat; this was true of the experiment as regards faba bean, but not as regards chickpea. The good N use efficiency of the wheat-sunflower rotation is attributable to the ability of the sunflower root system to use N from the lowest soil layers, thereby reducing residual N and increasing NUE values.

4. CONCLUSION

On a rainfed Vertisol under Mediterranean conditions, winter rainfall is closely related to wheat yield, which peaks when rainfall is around 450 mm, and declines with higher or lower winter rainfall. The wheat-faba bean rotation had the greatest effect on wheat at all N rates (higher yield, greater rotation effect and better yield stability), followed by the wheat-fallow rotation. No significant differences were recorded between the two rotations at an N rate of 150 kg N·ha⁻¹. The influence of chickpea on wheat yield was clearly smaller than that of faba bean, and generally closer to that of sunflower. Continuous wheat consistently recorded lower yields than two-year rotations, as well as causing a dangerous accumulation of NO₃⁻-N in the soil due to lower N use efficiency. Soil NO₃⁻-N levels in wheat-faba bean and wheat-fallow rotations were similar, and were both lower than those under wheat monoculture. Wheat-chickpea and wheat-sunflower rotations generated a smaller build-up of soil NO₃⁻-N, although in many cases concentrations were significantly lower in wheat-sunflower. This

highlights the poor N₂ fixing ability of chickpea, and the excellent complementary role of the wheat-sunflower rotation in terms of N use, since this rotation – together with wheat-faba bean – recorded the highest NUE values.

Acknowledgments: This work was funded by the Spain's Plan Nacional I+D (Proyect CICYT AGF97-0498). The authors thank Assistant Technicians Joaquín Muñoz and Auxiliadora López for their invaluable help and cooperation in the laboratory and in field work.

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