INNOVATIVE DOUBLE CROPPING SYSTEMS INCLUDING CAMELINA [*CAMELINA SATIVA* (L.) CRANTZ] A VALUABLE OILSEED CROP FOR BIO-BASED APPLICATIONS

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ABSTRACT: Cropping system intensification (i.e. double, mixed or relay cropping) is becoming an actual topic when dealing with non-food crops since it has been identified as a simple and remunerative way to avoid food versus bioenergy debate and consequent indirect land use change (iLUC). Within the European project COSMOS different types of rotation schemes have been tested in order to identify the most suitable for camelina to avoid iLUC and ensure satisfactory productivity. A 4-year trial has been set up in Italy (Bologna) and Greece (Aliartos) testing the feasibility of camelina double cropped with corn (Zea mays L.) in rotation with winter wheat (Triticum aestivum L.). At both locations, the earlier harvest of camelina compared with wheat allowed to successfully double crop corn afterward. While winter wheat resulted significantly more productive in Italy than in Greece (grand mean of all years and rotations), camelina and corn gave higher seed yields in Greece. The positive effect of crop diversification on wheat sole-cropping system resulted significant in Italy, when the double cropping of camelina before winter wheat allowed the latter to reach ~20% higher seed yields. In Italy, camelina despite moderate seed yields (grand mean: ~ 1.4 Mg DM ha-1), it had low input with higher energy value (25.15 vs. 10.94 GJ ha-1) and energy efficiency (3.55 vs. 1.17) than a very productive winter wheat.
Keywords: agricultural intensification, biodiversity, biobased economy, oilseeds, energy balance.

1 INTRODUCTION

Mediterranean farming systems rely extensively on winter cereal production (sole cropping), but the lack of real alternatives is leading not only to market price distortions, but also to an unsustainable intensification of agricultural practices and the subsequent overexploitation of natural resources and overreliance on external inputs, in a scenario of increasing vulnerability to climate changes. Whereas, there is evidence of clear benefits on soil quality, efficient use of natural resources, microbial diversity and ecosystem sustainability due to crop diversification. Crop diversification has however to meet not only sustainability targets from an environmental point of view but also from an economic perspective.

One way to pursue crop diversification is the intensification of cropping systems. Systems based on temporal intensification, such as double- and relay-cropping increase crop diversity, improve soil structure, reduce soil erosion, nitrate leaching, and P run-off, and enhance habitat for wildlife and pollinators [1]. Double- and relay-cropping systems can increase crop diversity without reducing the area used to produce food crops [2, 3], thus avoiding iLUC when one of the two crops is grown for non-food purposes. Double-cropping is defined as growing two crops in succession, in the same field, in the same season where the second crop is planted after the first crop is harvested; while relay-cropping is defined as a method of multiple cropping, where a crop is planted into an already established crop, whereby the two crops co-occur for a significant period of their growth the life [3]. In the Mediterranean region double cropping could be easily adopted, especially in irrigated lands where the summer crop could be provided by supplemental water. Otherwise, in the northern USA where the growing season is much shorter relay cropping is often preferred [4].

Camelina is an emerging oilseed crop which is attracting the interest of both farmers and biobased industries in relation to the peculiar qualitative characteristics of its seeds [5]. The unique fatty acid (FA) profile rich in polyunsaturated FAs and the high protein content make camelina seeds suitable to multiple end-uses [6]. From the agronomic point of view camelina is considered a very low input crop, with a wide environmental adaptability [7], and the availability of both winter and spring biotypes further enlarge this attitude [6].

Winter camelina types have been extensively studied as an alternative to fallow in the northern Great Plains [3,4,8] since their earliness allow an easy double or relay crop with typical summer staple crops, such as soybean or corn. Otherwise, in Europe, studies on the possible adoption of winter camelina in double cropping systems have never been carried out.

In the framework of the COSMOS project (G.A. 635405) new rotation schemes for camelina have been tested in the Mediterranean region to provide insights to farmers on this agronomic opportunity. The first results from a 4-year-experiment carried out in Italy and Greece on the technical feasibility of winter camelina double cropping with corn as well as on the beneficial effects of introducing camelina as an alternative to winter wheat sole-cropping system are reported.

2 MATERIALS AND METHODS

Similar rotation field trials were established in Italy (Bologna) and in Greece (Aliartos), in autumn of 2015 and they are still ongoing. The two experimental sites are

characterized by different climatic and soil conditions, as reported in Table I.

Table I: Locations, soil type, and main climatic characterization (30-year historical data) for the two test locations

Location (Country)	Coordinates	Soil type	Cumulative annual precipitation (mm)	Mean annual temp (°C)
Aliartos (Greece)	8°22'N, 23°6'E	Sandy loam	485	16.7
Bologna (Italy)	44°33'N, 11°23'E	Silty clay loam	613	13.4

Winter wheat sole-cropping system was compared with winter wheat preceded by camelina double cropped with corn. Each year the trials have been re-established on an existing winter wheat stand (*year 0*) allowing to compare the effect of sole-cropping vs. crop diversification (Fig. 1). Winter wheat (typical variety for each test location) and winter camelina (cv. Luna) were sown at the same time in late autumn, i.e. early November in Italy and early December in Greece, defined as the usual optimal date for cereals at each location. The establishment of corn succeeded immediately after camelina harvest. The agronomic management of winter wheat and corn have been defined as the optimal one at each trial site. Camelina agronomic management was the same at the two locations and consisted in a seeding rate of 5 kg ha^{-1} and a top-dressing application of 50 kg N ha^{-1} before stem elongation in February, while chemicals (i.e. herbicide, fungicide, insecticide) were never used. Corn (typical variety for each test location) was irrigated by means of sprinkler systems both in Italy and in Greece, while winter crops (i.e. camelina and wheat) were rain fed. At both locations all the crops have been harvested at full maturity and seed yield have measured and reported on dry matter basis.

A simplified energy balance to compare just the agricultural phase of winter wheat and camelina has been carried out only for the trials established in Italy. As energy inputs: tillage, sowing, fertilizing, chemical spraying and harvesting operations have been considered, adopting values from the literature. As energy outputs: the energy value of camelina seeds was assumed as 25 MJ kg^{-1}, as suggested by [4]; while for winter wheat a value of 14 MJ kg^{-1} was adopted.

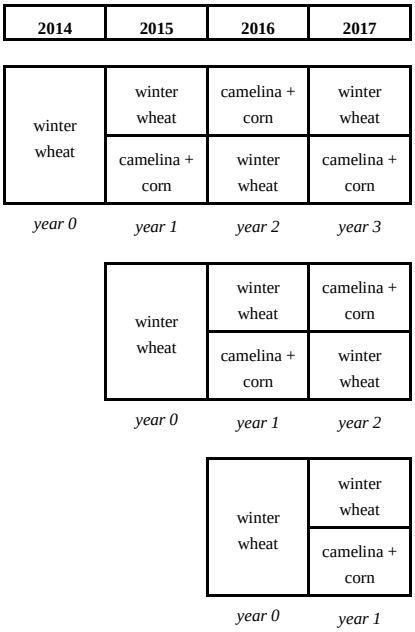

Figure 1: Field plot layout showing the 2-year cropping sequence at the two test sites, 2014–2017. This study was conducted with four blocks per site

3 RESULTS AND DISCUSSION

Camelina confirmed its earliness compared with winter wheat (Fig. 2), ranging from 10 d up to almost one month, depending on the location and growing season.

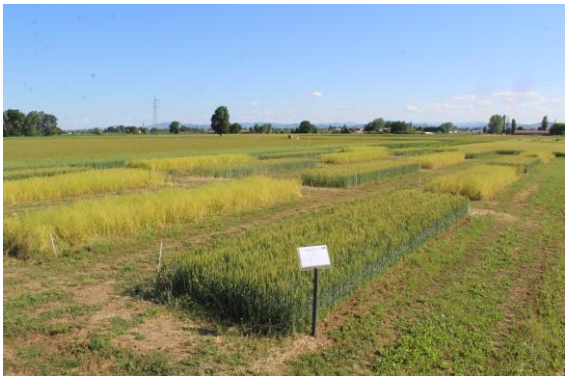

Figure 2: View of the rotation trials in Italy, where camelina is almost ready for harvest while winter wheat is still at milk stage (photo taken by F. Zanetti on the 25 May 2017)

The double cropping of corn, after camelina harvest, was always feasible, either in Italy and in Greece, by choosing an early maturity class hybrid (FAO 300). The seed yield of the tested crops varied significantly across test location; in particular, winter wheat was productive in Italy ($P \leq 0.05$), while camelina and corn reached significantly higher yields in Greece (Fig. 3).

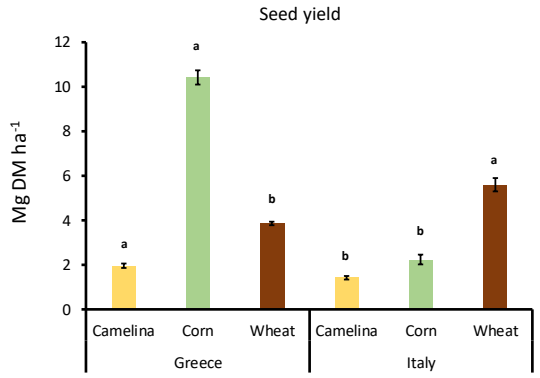

Figure 3: Mean seed yield (Mg DM ha^{-1}) of the three tested crops in Italy and Greece. Vertical bars: standard error. Different letters refer to statistically different means for the same crop species across the two locations (P≤0.05, LSD test)

The results of the energy balance carried out for Italy, comparing the agricultural phase of camelina and winter wheat, despite in this environment camelina reached the lowest seed yield and wheat the highest, corroborated those found in North Dakota (USA) by Berti at al. [3,4]. Camelina had the lowest inputs with only 9.9 GJ ha^{-1} of energy inputs compared with 38.8 GJ ha^{-1} of winter wheat. The very high productivity of winter wheat lead to a higher net energy value of camelina compared with wheat: 38.16 vs. 25.15 GJ ha^{-1}, for wheat and camelina, respectively. As expected, the energy efficiency of camelina was almost double than that of wheat, 3.55 vs. 1.98. Net energy values and energy efficiency reported in this study for camelina are in agreement with those of [3,4,8] who reported net energy values ranging from 15 to 27 GJ ha^{-1} and energy efficiency ranging from 3.1 to 4.6. The energetic evaluation of the double-cropping system (camelina + corn) as expected had much higher inputs related to the additional costs of seeding, harvesting, fertilizing, and irrigation used for corn. Thus, a careful evaluation of the crop following camelina in the double cropping systems should be carried out, with corn being particularly suitable to the Greek conditions while in Italy its production level was too low (~2.2 Mg DM ha^{-1}), and possible alternative species such as sunflower (*Helianthus annuus L.*) and sorghum (*Sorghum bicolor L.* Moench) might be considered.

The re-establishment every year of the rotation trials on a winter wheat stand permitted the evaluation of the crop diversification effect on wheat productivity in two out to the three considered growing seasons (i.e. 2016-17 and 2018-18), and excluding the effect of "year". A significant "location × preceding scheme" effect was (P≤0.05), with the yield of wheat grown in Italy positively influenced by the adoption of camelina + corn double cropping as preceding scheme, while in Greece differences between sole-cropping and double-cropping were not significant (Fig. 4). The present results partially contrast with those reported by [9] for experiments carried out in Montana and Kansas where winter wheat showed the same yield when preceded by fallow and winter camelina. Obviously our trials compared continuous wheat with preceding double crop of camelina and corn, thus the beneficial effect (+ 20% seed yield) found on the wheat production in Italy should be carefully evaluated, also in relation to the low production on corn which might have left some residual additional fertility at the soil level available for succeeding wheat.

Otherwise in Greece where corn production was five times that of Italy the positive effect of preceding double crop was not significant, but it is worth mentioning that wheat yield was neither decreased, and this is a very important finding for the future development of these new types of highly productive cropping systems.

The thorough evaluation of the beneficial effects of the double-cropping system, not only from a productive point of view but also from the environmental aspects is still an open question. As reported by [4] double- and relay- cropping systems increased biodiversity and reduced soil erosion potential, but also the economic revenue associated to these new systems should be considered for their reliable adoption by Mediterranean farmers.

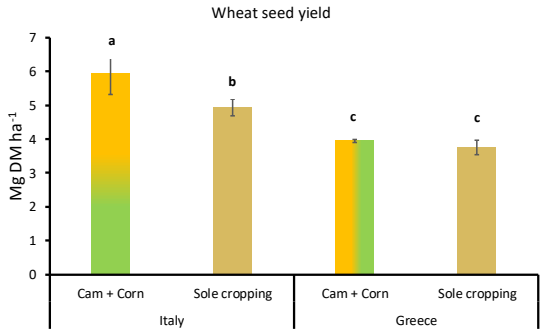

Figure 4: Winter wheat seed yield (Mg DM ha^{-1}) in Italy and Greece as influenced by preceding crop scheme (wheat sole-cropping vs. camelina + corn double-cropping). Vertical bars: standard error. Different letters refer to statistically different means (P≤0.05, LSD test)

4 CONCLUSIONS

This preliminary study showed that the emerging multi-purpose oilseed, camelina, could easily enter the Mediterranean rotation schemes, in view of its short cycle, low input requirements, and satisfactory seed yield. The possibility in the future to double crop camelina sown in winter with typical summer food crops in the Mediterranean region will avoid iLUC and thus increase the appeal of this species toward farmers and public opinion. The full evaluation of the proposed rotation schemes in terms of environmental and economic assessments will be the next step further to making camelina an important feedstock for the European biobased industry.

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7 COSMOS PROJECT LOGO

COSMOS
ADDING VALUE TO CAMELINA AND CRAMBE OIL