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Cultivar competitiveness in pea-oat intercrops under Mediterranean conditions

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ABSTRACT

Reducing interspecies competition and enhancing complementarity through cultivar selection in intercrops is important for achieving sustainable intensification. Under Mediterranean conditions, pea-oat intercrop has shown high land-use efficiency (LER). Field experiments were established under rainfed conditions in two locations in Greece for two growing seasons (2011–12 and 2012–13) to assess agronomic traits [date to flowering, plant height at stem elongation BBCH32, final plant height, and lodging], dry matter yield (DM), quality traits (protein, fat and ash concentrations, nitrogen free extracts), crop protein yield (CPY), and the competitive ability of three oat and three field pea cultivars in intercrops and sole crops. The intercrops produced on average 6.7% less DM than the oat sole crops, but had 27% higher CPY. However, interactions were found for the DM between the two locations, regarding species, cultivars and cropping systems, indicating that cultivars performed differently in sole crop and intercrops. Across locations, a pea-oat combination was the most consistent, showing the highest values of LER and monetary advantage index (MAI) that indicated its wide adaptation. Moreover, a second pea-oat combination showed specific adaptation to the warm and soil N-poor location. One testing environment favoured the high competitive ability of peas, whereas the other favoured the oat, possibly due to higher N-NO_3 availability. Intercropped oat flowered later, was shorted at the stem elongation stage, and lodged more than sole crops. On the other hand, peas flowered later and were taller at stem elongation stage, as well in final plant height in comparison to their peers in sole crop. Overall, the results highlighted the need of multi-environment trials to assess the effects of genotype × environment interactions in order to select compatible cultivars for maximizing the productivity and stability of the pea-oat intercrops.

1. Introduction

The biological and economic sustainability of ruminant farming in the Mediterranean region is challenged by the shortage of forage resources. Forages as diet components provide nutrients at low cost, maintain rumen function, thus supporting animal health, and add value to the products (Broderick, 1995; Yolcu et al., 2016). Legumes are very important constituents of forages because the European livestock sector has to reduce the import of protein from soybeans or rarer sources like fish meal (Westhoek et al., 2011). In this line, the use of improved plant material, aiming at both higher forage productivity and quality, is a potential solution (Tsiplakou et al., 2014). Intercropping systems, especially those employing cereals and legumes, have also major advantages compared to forage sole crops like better utilization of abiotic resources (Sadeghpour et al., 2014), higher and more stable yields (Lithourgidis et al., 2006, 2007), better land use efficiency (Vlachostergios et al., 2015), and complementarity in use of the available recourses (Hauggaard-Nielsen et al., 2001).

Under Mediterranean conditions, the combination of field peas (*Pisum sativum* L.) and oat (*Avena* spp.) showed high land-use efficiency (Dordas et al., 2012). In addition, in the same study, it was found that the pea-oat intercrop, at a seeding ratio 80:20, was superior in crude protein yield (CPY) compared to sole crops and pea-barley intercrop due to its higher crude protein concentration (CP). Carr et al. (2004) demonstrated that intercropping pea with barley or oat increased total CPY compared to cereal sole crops. The advantage of oat lies in their ability to uptake mineral nitrogen (N) from deeper soil layers due to faster and deeper root growth (Neumann et al., 2007); in this way,

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intercropped species differentiate their N-niche avoiding competition. On the other hand, peas usually increase their reliance on symbiotic N_2-fixation in low-N soils while their ability to fix N_2 in high-N environments is restricted (Carr et al., 2004; Li et al., 2006).

Cultivar screening can contribute significantly to increased productivity of intercropping systems by investigating and exploiting the genetic variability for intercrop adaptation. Response of cultivars to different agronomic systems, including intercropping, has been found to be variable (Sharma and Mehta, 1989; O'Leary and Smith, 1999). Crop competitiveness is a trait influenced by the genotype, the environment, and their interaction, and cannot be attributed to a sole plant trait. Rather, it is the result of several plant characters, like plant height, early vigour, light interception, leaf area index (LAI) and architecture, tillering, canopy structure, crop ground cover, earliness, nutrient use efficiency, lodging, and disease resistance (Asif et al., 2014). Among these traits, early vigour, fast growth rate, and plant height were directly linked to the competitiveness of the genotype (Cousens et al., 2003; Bertholdsson, 2005). However, traits useful in a sole crop could be questionable in intercrop systems. For example, lodging of peas is an undesirable character in sole crop, but it is of minor importance when peas are intercropped with oat which contribute to the erect habit of peas and act as a wind barrier (Baudoin et al., 1997). Differences between oat cultivars for plant height, lodging, and maturity were important determinants of forage yield and quality when oat was intercropped with vetch species (Assefa and Ledin, 2001).

Selection of cultivars for intercrops depends, to a great extent, on the information obtained by testing their performance across different systems and environments (Gebeyehu et al., 2006). Carr et al. (2004) underlined the necessity to study the combining ability of oat-pea cultivars in intercrops since only a limited number of them were tested in combination. While a good deal of research has been invested in the selection of intercropping compatible species, seeding ratios and cultural systems, the competitive ability and complementarity of intercropped cultivars and the consequent selection of the most matched have been overlooked or based on sole crop trials.

The aim of this work was to determine whether specific cultivar combinations of three oat and three field pea cultivars perform better than the respective sole crops in terms of dry matter yield and quality. To gain insights into intercrops' performance, indices assessing land use efficiency and competition or facilitation between different cultivars and cropping systems were employed.

2. Materials and methods

2.1. Site and experiment set up

Field experiments were conducted at adjacent sites during 2011–2012 and 2012–2013 growing seasons (hereafter 2012 and 2013) at Central (Larissa) and Northern Greece (Thermi). At Larissa (39°36′ N, 22°25′ E, 77 m a.s.l.), the soil was a Vertisol clay loam, with pH (1:1 in H_2O) 7.84, organic matter 1.56%, $N\text{-}NO_3$ 10 mg kg^{-1}, P-Olsen 12 mg kg^{-1}, K 131 mg kg^{-1} and $CaCO_3$ 1.3% at 0–30 cm depth, while the soil at Thermi (40°32′ N, 22°59′ E, 5 m a.s.l.) was a Typic Xerorthent loam, with pH (1:1 in H_2O) 7.40, organic matter 1.24%, $N\text{-}NO_3$ 38 mg kg^{-1}, P-Olsen 16 mg kg^{-1}, K 157 mg kg^{-1}, and $CaCO_3$ 3.5% at 0–30 cm depth. Soil samples were taken for analysis before seeding in mid-November. Table 1 presents the mean monthly temperature and monthly precipitation of the experimental locations during the two growing seasons.

Seedbed preparation included mould board plough, disk harrow, and cultivator. Seeding was conducted by hand sowing the mixture in every row at a planting depth of 2.0 cm, between 15 and 20 November in each location and growing season. No fertilization and irrigation were supplemented and weeds were suppressed by hand-hoeing when necessary.

Table 1
Mean monthly temperature (°C) and monthly precipitation (mm) and during the two growing seasons of experimentation at Central (Larissa) and Northern (Thermi) Greece.

	Larissa		Thermi			Larissa		Thermi	
	Temperature (°C)					Precipitation (mm)			
Month	2012	2013	2012	2013		2012	2013	2012	2013
November	6.9	13.0	8.0	15.3		2.0	10.9	8.9	3.4
December	4.7	6.3	6.7	9.0		30.7	84.8	42.9	35.6
January	1.7	5.7	3.7	7.8		14.2	13.7	35.8	13.2
February	4.7	5.8	5.2	8.9		72.4	55.4	9.2	97.2
March	11.0	11.7	10.7	10.7		37.9	22.5	32.8	36.4
April	17.9	17.7	15.1	15.2		20.5	2.5	52.6	11.0
May	21.3	24.7	19.8	22.0		10.2	19.6	59.6	7.4
Mean	9.7	12.1	9.9	12.7	Total	187.9	209.4	241.8	204.2

The experimental design was a randomized complete block (RCB) design with 15 treatments (three oat sole crops, three pea sole crops, and nine pea-oat intercrops) and three replications. The experimental plots consisted of six rows, 4 m long and with 0.25 m spacing between rows, and were separated by 1 m buffer zone. Blocks were separated by 2.5 m buffer zone. The number of seeds sown for pea and oat sole crops was 240 and 405 seeds m^{-2}. For the intercrops, the number of seeds sown was 192 and 81 seeds m^{-2} for pea and oat, respectively, corresponding to a pea-oat ratio of 80:20. The applied ratio of the intercrops was selected because it was proposed as the most productive for crude protein and achieved the best LER for the local conditions (Dordas et al., 2012).

The three oat cultivars were Kassandra, Flega, and Pallini (Cereal Institute, Thermi, Greece); cv. Kassandra is an *Avena byzantina* Koch, while Flega and Pallini belong to *Avena sativa* L. (Bladenopoulos, 2010). The three normal-leafed field pea [*Pisum sativum* subsp. *arvense* (L.) Asch.] cultivars were Dodoni, Olympos, and Ithomi (Institute of Industrial and Fodder Plants, Larissa, Greece). Oat cultivars were selected for their contrasting maturity (Flega: very early, Kassandra: mid-season, and Pallini: late-season) and plant height [Pallini, short (90–100 cm); Flega, moderate (110–120 cm); and Kassandra, tall (120–130 cm)]. Field pea cultivars were selected for their wide adaptability and the high forage yield potential in sole crop.

2.2. Agronomic, yield and quality measurements

Agronomic traits were determined concurrently on oat and peas in 10 randomly-selected plants per plot. The average of the 10 values constituted the value for each plot. Measurements took place only at Larissa and were the following:

- Height at stem elongation (SE), it was measured at oat stem elongation growth stage (BBCH 32, main stem node 2 at least 2 cm above node 1, Lancashire et al., 1991) as the distance from the soil surface to the top of the plant canopy and considered as an early growth index.
- Final plant height (FPH), it was measured at forage maturity (BBCH 77) as the distance from the soil surface to the far end of plant.
- Days to Flowering (DtF), in oat it were the number of days from plant emergence to 50% spike full emergence from the flag leaf (BBCH 65). In peas, the number of days from plant emergence to the day of the first open flower (sporadically within the population, BBCH 60) was counted. This trait was regarded as an index of earliness.

Lodging percentage (Lodg), it was determined in oat sole crops and intercrops at maturity. It was expressed in percentage with 0% to indicate fully-upright plants and 100% to correspond to completely lodged plants. No differentiation for lodging percentage was found for peas in sole crops; the three peas were heavily lodged (data not shown).