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Assessment of the benefits of frost-sensitive companion plants in winter rapeseed

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ABSTRACT

The intercropping of rapeseed with frost-sensitive companion plants (CP) has recently been proposed as a way to mitigate the negative environmental impact of rapeseed crops. Using mixed-effect linear models, we compared the yield and weed amounts of rapeseed intercropped with different CP species with that of rapeseed as a sole crop in an unique dataset of 79 field experiments covering a wide range of climate, soil and practices conditions in the northwestern part of France, from 2009 to 2015. Bayesian model averaging procedure was used to determine the relative contributions of sites characteristics to the effects of intercropping.

Before winter, field pea and faba bean had accumulated the largest amounts of dry mass, with more than 100 g m^{-2}. Rapeseed biomass was reduced by 56% by non-legume CPs and by only 18% by legume CPs, the largest decrease being caused by pea. Non-legumes decreased the nitrogen nutrition index of rapeseed by 7%, whereas pea and faba bean increased this index by 6% and 3%, respectively. Intercropping with non-legume and legume CPs reduced weed amounts by 52% and 38% respectively, with no difference between CP species. Non-legume CPs decreased rapeseed yield at harvest by 0.58 t ha^{-1}, whereas faba bean and faba bean + lentil increased yield by 0.16 and 0.12 t ha^{-1} respectively, when fertilized at the recommended rate. Intercropping with faba bean, lentil or a mixture of both made it possible to reduce nitrogen applications by 30–40 kg ha^{-1} with no significant decrease in rapeseed yield. Faba bean and faba bean + lentil mixtures had the best overall performance. This work suggests that intercropping rapeseed is promising, particularly in soils with low nitrogen content with an early sowing date in the late summer.

1. Introduction

Almost nine million hectares are planted with winter rapeseed in Europe (the 5th most cultivated species) and 1.5 million hectares of the area under this crop are found in France (FAOSTAT, *faostat.fao.org*). Rapeseed is considered a good crop for preceding wheat, in particular, within the rotation, for several reasons: its deep rooting system structures the soil; its residues have a high nitrogen content, which is of benefit to the next crop; in cereal-dominated rotations, it breaks the cycle of diseases and weeds associated with cereal crops; and it provides high economic returns, thanks to the biofuel market (Hebinger, 2013). However, rapeseed also has negative effects on the environment. Pesticides against many pests, weeds and diseases are applied in both fall and spring, with a treatment frequency index of 5.6 in France in 2014 (Agreste, 2016), second only to that for field-cropped potatoes. In France, the mean mineral nitrogen fertilizer application in spring in 2011 was 169 kg ha^{-1}, and rapeseed is the field crop with the third highest requirement for nitrogen fertilizer (Agreste, 2014). This high nitrogen requirement, which is mostly met through the use of synthetic fertilizers, decreases the energy balance of rapeseed biofuel (van Duren et al., 2015). All these aspects call into question the overall sustainability of rapeseed cropping and suggest that alternative crop management techniques should be developed, to reduce the reliance on pesticides and fertilizer use.

Planting mixtures of plants is one way to reduce the environmental impact of agriculture, by improving crop productivity and pest regulation (Gaba et al., 2015; Malézieux et al., 2009). Companion plant (CP) intercropping involves growing a cash crop with another plant that is not harvested, to confer a set of benefits on the crop and the environment (Hartwig and Ammon, 2002; Liebman and Dyck, 1993). The cropping of rapeseed with simultaneously sown frost-sensitive CPs has been proposed as a means of reducing pesticide and fertilizer use

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(Cadoux et al., 2015; Lorin et al., 2016, 2015). The rapeseed and the CP grow together until the CP is killed by frost or herbicide during the winter. The following spring, the rapeseed grows alone, like a conventional sole crop, until harvest. In the fall, the CP provides greater soil coverage and controls weeds (Cadoux et al., 2015; Liebman and Dyck, 1993; Lorin et al., 2015; Verret et al., 2017). The presence of a large amount of CP biomass can reduce damage due to insect pests in the fall, probably through visual and/or olfactory confusion (Cadoux et al., 2015; Finch and Collier, 2000). In spring, mineralization of the killed CP residues contributes to the nitrogen nutrition of the rapeseed crop (Cadoux et al., 2015; Lorin et al., 2016).

Several CP species, including members of the legume family in particular, including faba bean, lentil, vetches and berseem clover, have already been tested for intercropping with rapeseed (Cadoux et al., 2015; Lorin et al., 2016, 2015). Legume species are considered good candidate CPs because they produce biomass and compete with weeds without competing strongly with the main crop for nitrogen, thanks to their ability to fix nitrogen from the atmosphere (Corre-Hellou et al., 2011; Hauggaard-Nielsen et al., 2001). However, Lorin et al. (2015) showed that CP performance, in terms of biomass production, weed control and nitrogen release, differs considerably between species. However, studies on rapeseed intercropping have not yet provided sufficient information about the variability of performance over a broad range of contexts.

The performance of the intercropping system may also be subject to interactions between the components of the system (the crop, companion plants, and weeds), agricultural practices and the environment (Gaba et al., 2015; Lithourgidis et al., 2011; Wilke and Snapp, 2008). Soil fertility is a key factor determining CP performance, as it affects competitive interactions between plants. For example, Lorin et al. (2015) showed that 11 species and mixtures of species had very different abilities to control weeds, depending on soil mineral nitrogen content at sowing (Lorin et al., 2015). In another study, seven clover species were found to control weeds more effectively in nitrogen-poor than in nitrogen-rich soils (Ross et al., 2001). Climate conditions also determine CP performance, but this effect is often nested in a "study year" effect. For instance, 12 CP species were found to compete with maize to different extents depending on the year (Abdin et al., 2000). Drought affects the performance of a maize living mulch system including kura clover (*Trifolium ambiguum*), a species that behaves well in dry environments (Ziyomo et al., 2013). An understanding of the effects of agropedoclimatic conditions on the performance of intercropping systems is crucial for selection of the best CP species in a given context.

The primary objective of this study was to quantify the effects of CPs on weed control, rapeseed competition, nitrogen nutrition and grain yield, in rapeseed crops, over a broad range of contexts. We hypothesized that the amount of CP biomass accumulated before winter would be a key intermediate variable strongly related to various aspects of CP performance, such as competition with rapeseed, weed regulation and N supply to the crop (Cadoux et al., 2015; Lorin et al., 2016, 2015). Our secondary objective was to analyze the variability of the effects of these intercropping systems between trials and to rank the respective roles of CP species, climate and soil conditions, agricultural techniques, and the interactions between these variables, with the aim of facilitating the selection of CP species well-adapted to the local context.

2. Materials and methods

2.1. Field experiments

From 2009–2015, 79 trials (1 trial = 1 site × 1 year × 1 experimental design) were conducted at several sites located to the north of a diagonal line running between Bordeaux and Strasbourg, in France (Fig. 1). Local agents managed the trials, with an experimental design best suited to the available workforce resources. The studies were designed as replicated randomized blocks or on-farm non-replicated side-by-side strips. Seventeen different species of CP and 42 mixtures of two to five species were assessed in trials exploring a wide range of plant characteristics in a diversity of soil and climate conditions (see Appendix A in the Supplementary material for the list of the different companion plant species and mixtures of species tested in the trials). The main CP species and mixtures were: spring faba bean (*Vicia faba*), lentil (*Lens culinaris*), spring field pea (*Pisum sativum*), and three mixtures of legume species consisting of faba bean + lentil, grass pea (*Lathyrus sativus*) + fenugreek (*Trigonella foenum-graecum*) + lentil (GFL), and spring common vetch (*Vicia sativa*) + purple vetch (*Vicia benghalensis*) + berseem clover (*Trifolium alexandrinum*, VVC). Non-legume species were gradually abandoned over time, because they competed too strongly with the rapeseed crop, and legume species were preferred for the trials. Companion plants were sown at 75% the rate generally used for monocultures of the species concerned. For legume mixtures, the sowing density of each species was reduced proportionally, according to the number of species. The control treatment was a rapeseed sole crop. Rapeseed cultivar, sowing density, tillage, weed management practices, pest and disease control with chemical pesticides and other agricultural practices were adapted to local conditions. In early spring, the nitrogen fertilizer requirements of the rapeseed crop were determined by the nitrogen balance sheet method (Reau and Wagner, 1998). Two modes of fertilization were assessed: (i) the recommended dose, and (ii) a reduced dose, 30–40 kg ha^{-1} less than the recommended dose. As control treatment(s), each trial had either (i) a rapeseed sole crop treated with the recommended dose, (ii) a rapeseed sole crop treated with the reduced dose, or (iii) both these control treatments.

2.2. Measurements

Before winter, whole plants of rapeseed, the CP and weeds were sampled with a single 0.5–1 m^2 quadrat for each treatment in each block. In trials without replicates, measurements were made with three to four quadrats per treatment strip. The aerial dry mass of each component was determined after drying at 80 °C for 48 h, and N content was determined by the Dumas method. The nitrogen nutrition index (NNI) of the rapeseed was determined from its aerial dry mass and N content, according to the formula proposed by Colnenne et al. (1998):

$$NNI = \frac{Rapeseed\ \ N\ \ content}{4.48 \times (rapeseed\ \ dry\ \ mass)^{-0.25}} \tag{1}$$

At maturity, each treatment was harvested separately with a combine harvester, and yields were recorded. Not all measurements were performed systematically in all trials, depending on the resources of the institutions concerned.

2.3. Trial characteristics

For each field trial, local agents recorded a set of characteristics, including soil characteristics and agricultural practices (Table 1) (see Appendix B in the Supplementary material for a complete description of the trials, including the types of measurement performed). Daily climatic data from the nearest meteorological station to each trial, including temperature, rainfall, radiation and evapotranspiration, were acquired from Météo-France. They were summed over the period of CP growth, extending from sowing date to winter sampling date.

2.4. Indices measuring the effects of companion plant intercropping

Intercrop performance was estimated with four indices. The competition experienced by rapeseed in intercrops before winter was analyzed by measuring the effect of the CP on rapeseed dry mass and NNI before winter, as follows:

$$R_{Rapeseed\_DM} = Rapeseed\ \ dry\ \ mass\ _{Intercroppedrapeseed}/Rapeseed\ \ dry\ \ mass\ _{Solerapeseed} \tag{2}$$