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# Undersowing winter oilseed rape with frost-sensitive legume living mulch: Consequences for cash crop nitrogen nutrition

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ABSTRACT

The use of legume cover crops as green manure is often seen as an effective means of supplying nitrogen to the following crop. As winter oilseed rape requires a large amount of N in the spring, the introduction of frost-sensitive legume living mulch (killed off during the winter) is a promising way of decreasing mineral N fertiliser inputs. The aim of this study was to assess the supply of biological N to rape during the spring from several frost-sensitive legumes, grown as intercropped living mulches.

We carried out a field trial over two growing seasons before sowing, comparing seven legume species and three legume mixtures intercropped with rape, and two levels of soil mineral N. The presence of legumes, living during the autumn and dead during the spring, resulted in 20–40 kgN ha$^{-1}$ more nitrogen uptake in oilseed rape, by the end of flowering, compared to rape grown as a sole crop. Moreover, the use of $^{15}$N-labelled nitrogen fertiliser showed that this increase in rape N accumulation was due to the mineralisation of legume residues, but also to other mechanisms such as increase in fertiliser-N recovery and in soil organic matter mineralisation.

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## 1. Introduction

Intensive agricultural production is highly dependent on N fertilisation, but only 30–50% on average of the nitrogen fertiliser applied, is taken up by the crop (Tilman et al., 2002). N is lost through various mechanisms, leading to changes in biogeochemical N fluxes that greatly destabilise the Earth's homeostasis (Steffen et al., 2015) and affect ecosystem functioning (Tilman et al., 2001; Cameron et al., 2013).

One of the main arable crops grown in Western Europe, winter oilseed rape, requires large amounts of N fertiliser. In France, the mean rate of N application reached 169 kgN ha$^{-1}$ in 2011 (AGRESTE, 2014). The area planted with rape has rapidly increased in recent decades, owing to the use of this crop as a biofuel (Schott et al., 2010; Van Duren et al., 2015). So there is an urgent need to decrease mineral fertiliser inputs and increase the efficiency of fertilisation practices for rape.

Organic mulches of plant residues provide an interesting source of biological N for cash crops. Legumes, grown as cover crops or as green manure, have frequently been shown to increase the N uptake of the following cash crop, particularly for spring crops (Liebman et al., 2012; Nagumo and Nakamura, 2013; Amossé et al., 2014). However, as the crop preceding rape, sown in late August in France, is most often a cereal, harvested in July (Schott et al., 2010), the period available for growing a cover crop is very short, thus limiting the amount of legume biomass that may be produced.

Intercropping with frost-sensitive legume living mulch (Cadoux et al., 2015; Lorin et al., 2015) may be an effective way of providing the rape crop with biological N during the spring. After a period of simultaneous growth in autumn, winter frost should kill off the legume, thus providing a source of N for mineralisation, derived from biological fixation or mineral N absorption, for use by rape in the following spring. Moreover, as shown in previous studies (Cadoux et al., 2015; Lorin et al., 2015), this technique should provide other ecosystem services, such as weed regulation and lower levels of rape winter stem weevil damage. For such a system to be effective, the living mulch species should fix and/or absorb a significant amount of N within a short period of growth (from the end of August to mid-November), minimising competition with rape for N uptake. The symbiotic N fixation system of legumes generally results in an absence of competition with non-legume crops, particularly at low levels of mineral N availability (Naudin et al., 2010). Moreover, it is assumed that the decrease in N-fertiliser need depends on the synchronism between N mineralisation dynamics from legume residues and the dynamics of rape N uptake.

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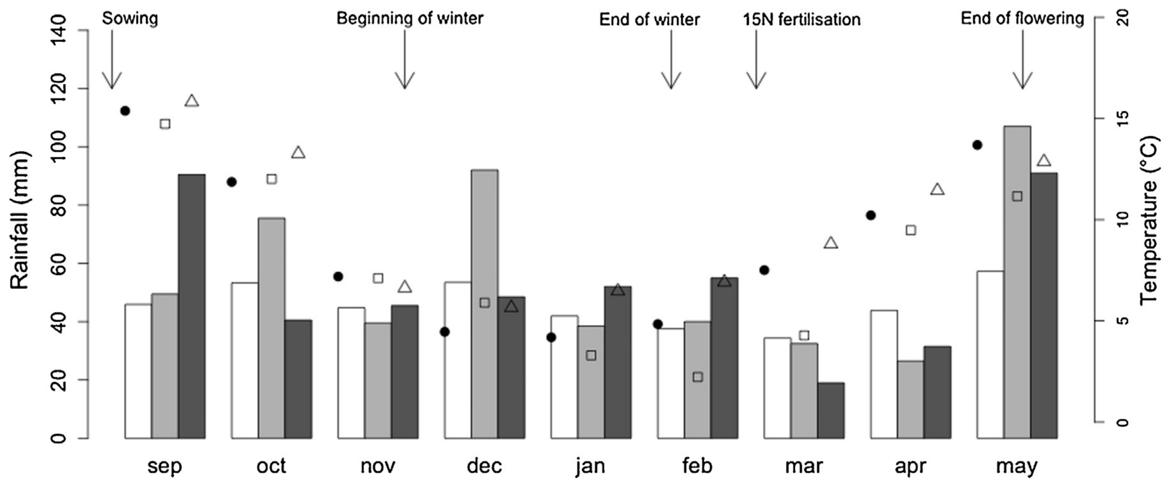


**Fig. 1.** Rainfall and temperature at the Grignon station in the growing seasons of 2012–2013 and 2013–2014, as compared with average data (1993–2013). The bars indicate the cumulative monthly rainfall (white: average for 1993–2013; light grey: 2012–2013, dark grey: 2013–2014). The symbols above the bars indicate the mean temperature of the corresponding growing season (●: 1993–2013, □: 2012–2013, Δ: 2013–2014).

In rape-legume intercrops, the organic N present in the legume residues remains at the soil surface as dead mulch, resulting in a different pattern of mineralisation dynamics from what is observed when these residues are incorporated into the soil (Coppens et al., 2006). The incorporation of legume residues may lead to higher (Yamawaki et al., 2014) or lower (Corbeels et al., 2003) levels of N mineralisation, depending on the quality of the residues. Moreover, Dejoux et al. (2000) showed that a fraction of the N derived from dead rape leaves that fall from the plant during the winter (with a low C:N ratio) was reabsorbed by rape during the subsequent spring, potentially providing several dozen kgN $ha^{-1}$. This suggests that non-mature legume residues, with their low C:N ratio (Tribouillois et al., 2015), could provide significant amounts of N to rape crops.

The aim of this study was to assess the supply to an intercropped rape crop of biological N from frost-sensitive legume living mulch, during the spring. We compared the effects of different legume species in various conditions of inorganic soil N availability before sowing.

## 2. Materials and methods

### 2.1. Field experiment

A field trial was carried out during two growing seasons in 2012–2013 and 2013–2014 at the INRA experimental station at Grignon (48.9°N, 1.9°E) in the Paris basin. The soil was an orthic-luvisol (FAO classification), with 250 g $kg^{-1}$ clay, 670 g $kg^{-1}$ silt and 80 g $kg^{-1}$ sand in the uppermost 30 cm (for a precise description, see Lorin et al., 2015). The soil N level before sowing reached 33 and 30 kgN $ha^{-1}$ in the 0–30 cm layer, 24 and 11 kgN $ha^{-1}$ in the 30–60 cm layer and 18 and 4 kgN $ha^{-1}$ in the 60–90 cm layer, in 2012 and 2013, respectively.

The two growing seasons were characterised by higher cumulative rainfall than the last 20-year average and a drier than usual early spring period (in March and April, Fig. 1). The months from January to May in 2013 were colder than the 20-year average. From early December 2012 to February 2013, the mean temperature was below 0 °C for a period of 14 days. The minimum temperature recorded was −3.8 °C. During the winter 2013–2014, no day had a minimum temperature below 0 °C, the coldest temperature recorded being 0.1 °C in early December.

### 2.2. Experimental design

Seven species of legume, sensitive to local average frost levels, were compared as intercrops with rape: fenugreek (*Trigonella foenum-graecum*, cv. Fenusol), spring faba bean (*Vicia faba*, cv. Espresso), grass pea (*Lathyrus sativus*, cv. Fertigess), lentil (*Lens culinaris*, cv. Fentille), field pea (*Pisum sativum*, cv. Rif), berseem clover (*Trifolium alexandrium*, cv. Tigri), spring common vetch (*Vicia sativa*, cv. Marianna). Treatments also involved three legume mixtures, intercropped with rape: lentil-grass pea-fenugreek, lentil-faba bean and common vetch-faba bean-berseem clover. A control treatment, with oilseed rape as a sole crop, was also included in each trial.

Legumes were broadcast sown at 75% of the recommended rate for a sole crop, and the seeds were incorporated into the uppermost 3 cm of soil by light tillage. For legume mixtures, the sowing density of each species was reduced proportionally, according to the number of species. Rape (*Brassica napus*, cv. Alpaga) was then sown at a density of 50 seeds $m^{-2}$, in accordance with local practices. The legumes and the rape were sown the same day (i.e. August 23rd, 2012 and August 22nd, 2013). We compared different mineral N availabilities in the soil, by applying 100 kgN $ha^{-1}$ fertiliser (as ammonium nitrate) to half of the trial just before sowing, the other half of the plots not being fertilised. Finally, the crop was irrigated to ensure regular emergence, at a rate of 50 mm $ha^{-1}$ in 2012 (25 mm $ha^{-1}$ on August 28th and 25 mm $ha^{-1}$ on September 5th) and 20 mm $ha^{-1}$ in 2013 (on August 27th).

The 22 treatments – 10 living mulches intercropped with winter oilseed rape and 1 sole rape crop, under two levels of soil mineral nitrogen content before sowing – were organised in a split plot experimental design with two factors: legume living mulch species and soil mineral nitrogen content before sowing. The trial included three replicates and randomisation for the legume factor. The plot size was 3.5 m × 12 m.

Pests and diseases were controlled by the application of appropriate pesticides. Each year, a single application of 1.5 L $ha^{-1}$ Kerb flo (propyzamide, Dow AgroSciences) was performed at the beginning of winter, to kill off cereal volunteers. No herbicide specific against dicots was applied in autumn, to prevent damage to the legumes, but weed competition was negligible both years. The low temperatures of the 2012–2013 winter were sufficient to kill off all the legume plants. However, the winter of 2013–2014 was unusually mild and only field pea was killed off (common vetch and berseem clover were partially killed off), thanks to the low tem-

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