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Designing and Evaluating Arable Cropping Systems with Cash and Cover Crop Legumes in Sole Crop and Intercrop to Improve Nitrogen use Efficiency



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Objectives

Increasing concern about climate change and environmental impacts requires transformation of cropping systems by for example introducing more legumes (grain legumes or cover crop forage legumes) to increase benefits from N_2 -fixation and break crop effects. Legumes could be grown alone or in intercropping known to use resources more efficiently when species do not compete for exactly the same. For instance, correct rotational position of legumes needs to be carefully analysed to design relevant solutions maximizing their benefit. The main objective of our work was to design and evaluate prototypes of arable systems including legumes using jointly field experiments and crop modelling.

This paper aimed at synthesizing:

- i. Impact of sole grain legume at the rotation level,
- ii. Potential of grain legume intercrops for improving yield and cereal protein content and
- iii. Potential of cover crops including intercropped forage legume to achieve simultaneously nitrate capture and green manuring ecosystem services.

Materials and Methods

Two 6-year field experiments were initiated at INRA Toulouse (SW France) in 2003-2004 to study the rotational effects of grain legumes (in sole crops and intercrops) and cover crops (green manure or catch crop function) according to N use efficiency and medium-term soil fertility. The cropping system design was based on a three-year rotation in low input system with each crop grown each year allowing climatic repetition. Six rotations were compared, differentiated by the frequency of

legumes in the rotation and the presence or absence of cover crop between cash crops. Crop management was based on decision rules in order to adjust technical acts to the soil and crop status and in particular adjusting N application rates to the preceding crop. Simulations at the rotation time scale were carried out using the STICS soil-crop model. The main processes involved in the water and N dynamical budgets are taken into account at the same time [1].

Complementary experiments with intercrops were established from 2001 to 2010 with a large range of combinations (durum wheat, bread wheat or barley intercropped with pea or faba bean) with various cultivars, sowing densities and N treatments leading to a large range magnitude and dynamics of N availability. Grain yield and cereal grain protein content as a quality criteria were used to evaluate the efficiency of the intercrops over the sole crop. The percentage of N derived from N_2 -fixation of legumes was estimated with ^{15}N dilution method altogether with nitrogen content in plant and soil to determine N balance [2].

In addition others experiments were conducted in three French experimental sites with contrasted climate conditions and soil characteristics for analysing cover crops effects. Ten cover crop species (five legumes and five non-legumes) with a rapid growth rate and contrasted shoot/root architectures were evaluated in sole crops and in bi-specific substitutive mixtures and compared to a bare soil as control. Biomass, N acquisition, C: N ratio and soil mineral-N were measured and ecosystem services of N management were assessed using both experimental and modelling data [3].

Results and Discussion

Winter and spring legume preceding crop show positive effects on durum wheat, due to:

- i. Higher soil mineral-N availability at wheat sowing and
- ii. Potentially breaking of cereal diseases cycles.

However, higher soil mineral-N levels both at harvest and in November after legume crops increased the potential risk of nitrate leaching which was efficiently reduced by the introduction of cover crops. Simulations of nitrate leached during the whole drainage period after autumnal destruction of cover crop mixtures did not differ significantly from those after non-legume sole crops and remained significantly lower than those under bare soil, especially for mixtures with turnip rape which benefitted greatly from being in mixtures. Legume sole crops were less efficient to reduce N leaching but their effect was still significant in comparison to bare soil which confirms that concerning nitrate leaching it is better sowing a legume cover than maintaining a bare soil.

The irrigated soybean crop did not increase the risk of nitrate leaching under the present growing conditions, mostly due to:

- i. A late growing cycle and
- ii. An efficient N uptake of mineral-N coming from soil mineralization, in complement to N₂-fixation.

Cover crops were particularly efficient during wet winters because the more the drainage volume, the more the reduction of nitrate leaching and nitrate concentration in leached water. N release from cover crop residues could be sufficient to compensate in a great part the pre-emptive competition for soil mineral-N when destroyed before winter. Overall, prediction of mineralized-N from cover crop residues was significantly higher for mixtures than for non-legume sole crops demonstrating the green manure ecosystem service.

Intercrops experiments showed that the total intercrop grain yield was almost always higher than that of the mean sole crop (3.3 vs. 2.7 Mg ha⁻¹ respectively) and similar result was found with accumulated N (121 vs 101 Kg N ha⁻¹ respectively) with a proportion of cereal at harvest higher than 50%. Our results confirmed that intercropping was more efficient than sole cropping without N fertilization or when N was applied late during cycle mainly due to dynamic complementarity: i) for light use (up to 10%) and ii) in N sources acquisition. Cereal grain protein concentration was significantly improved in intercrop compared to the respective sole crop (11.1% vs. 9.8%

respectively) and the lower the sole crop value the higher the increase in the intercrop. This increase in intercropping was due to: i) a lower cereal grain yield in intercrop than in sole crop (1.9 vs.2.9 Mg ha⁻¹ respectively) and ii) a quite similar (ca. 90%) amount of available soil N for the cereal in both systems because of a high legume N₂-fixation rate in intercrop (75% compared to 62% for the sole cropped legume).

Conclusion

Altogether with legume sole crops, intercropping a legume and a non-legume is interesting both for grain production and cover crops ecosystem services to design innovative cropping systems. This is due to the complementarity between species in improving use of N-resources especially in low available N systems. Indeed, bi-specific cover crop with a legume can provide good compromises between nitrate capture and green manuring ecosystem services by recycling the soil mineral-N in good synchrony with the succeeding cash crop. In a similar way, intercropping for grain production provided compromises between grain yield improvement, cereal grain protein content increase and proportion of the two species at harvest.

However, a number of factors still needs to be optimized in order to propose optimized future cropping systems including intercrops like: i) species and cultivars, ii) correct rotational position to not increase pests and diseases and also iii) sowing practice (e.g. alternate row sowing or mixture within each row, density of each component, width between rows,...). These choices depend on specific goals like for grain production the maximum total yield, the global protein production or the highest wheat grain protein content while for cover crops the choice of a mixture must be adapted according to site's soil and climate conditions, priorities of fallow-period management and services desired.

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