Using sensors to support the introduction of legumes for improving the sustainability of Spanish rotations by enhancing efficiency of nitrogen and water use (RESUENA)

This project is included in the research line 'water and nitrogen management in cropping systems' and it is coordinated with a project from INIA to favour introduction of legumes in crop rotations. The project are financed by the Spanish Nacional Research Plan and will last until the end of 2026.

Summary

Replacing cereal grains by pulse grains in the rainfed rotations

Almost 30% of the Spanish agricultural surface is destined to rainfed cereal grain production (MAPA, 2020), mostly wheat and barley. In this rainfed areas, maintaining sustainability is a necessary challenge to face given the high economic and environmental cost of the excessive use of fertilizers and the uncertainty about the availability of water, but also due to the lack of biodiversity. A first decision could be replacing some cereal grain crops by grain legumes in the farm crop rotation. The savings that the introduction of legumes implies due to their low demand for N fertilizers is well known and strongly recommended by 'Green Deal' and 'Farm to Frok' strategies, however the N contribution (i.e. fertilizer saving) for the following crop continues to be a source of uncertainty. On the one hand, the amount of N fixed and incorporated in the cultivation system depends on the legume species/landraces and the biomass accumulated (Anglade et al., 2015). On the other hand, another important factor in the N release rate, either from the nodules or from the incorporated residue, is the type of tillage carried out. Previous reverse-type work accelerates mineralization but can cause N to be released when the needs of the next crop are low; while less intensive work delays the release of N and can allow a better synchronization with the demand of the subsequent crop (Quemada and Gabriel, 2016). Because of that the characterization of a broad list of species and landraces is necessary in order to improve a proper selection (Bellucci et al., 2021). Some information is already available with respect to the characterization of vetches (Vicia sativa L.; de la Rosa et al., 2021; de la Rosa and González, 2010), chickpeas (Cicer arietinum L., Varshney et al., 2019) or lentils (Lens culinaris Medik.; Lázaro et al., 2001), among others, which in general are species well adapted to the area and the drought conditions in which the plants will be established (de la Rosa et al., 2020). Finally, the economic impact of introducing a legume in the rotation must be considered based on the fertilizer saving but also based on the grain yield and grain quality of the following crop. Legume production in Spain has decreased during the last decades, and now Spain is a net importer of grain legumes for human and animal feeding (MAPA, 2020). Total surface cropped with chickpea and lentil (two of the most important legumes in the Spanish gastronomy) rounds 100.000 ha together, less than the 0.6% of the total Spanish arable lands (MAPA, 2020). However, the changes in the dietary habits during the last decade (going back to the Mediterranean diet, lost during the second half of the 20th century (de la Rosa et al., 2017)) and the increase of the demand of quality and proximity products is also raising the demand of local grain legumes (Clément et al., 2018). Because of that, it is important to identify landraces well adapted (even considering that the amount of rainfall is decreasing and with more erratic distribution) and with high yield and good quality to reduce (or even improve) the economic impact of their inclusion in the crop rotation.

Including legume cover crops in the irrigated rotations

A second way to increase the biodiversity and sustainability in the irrigated lands is the inclusion of cover crops. Many irrigated systems in the central peninsula based on herbaceous crops have evolved to a simplification of rotations, mainly supported by summer crops that leave the soil bare or fallow during the autumn-winter period. In previous studies carried out in projects of the National Plan, it has been observed that the substitution of fallow by cover crops can improve the sustainability of these high-input systems by recycling nutrients (Gabriel and Quemada, 2011), mitigating the leaching of nitrates (Gabriel et al., 2012; Gabriel et al., 2016), improving the soil quality and carbon sequestration (García-González et al., 2018) and improving the mycorrhization capacity of the productive crop with respect to the fallow (García-González et al., 2016). As a consequence, in collaboration with nearby research groups, we have observed that cover crops allow to mitigate the gaseous emissions of the system if they are combined with adequate fertilization practices (Guardia et al., 2016) and have been identified as adaptation strategies to climate change and mitigation of greenhouse gas emissions (Sanz-Cobeña et al., 2017; Kaye and Quemada, 2017). Other advantages associated with cover crops and observed by different research groups are the reduction of diseases (Motisi et al., 2009) and weed control (Hollander et al., 2007). Previous projects have shown that a limitation for the introduction of cover crops in irrigation systems based on summer crops is the lack of time between the harvest of the main crop and the arrival of winter to sow it. For this reason, it is important to identify species and landraces that could be able to grow fast before winter (even under not favorable conditions), in order to cover faster the soil and extract as much nutrients as possible, improving nutrient recirculation and soil properties (as carbon sequestration) but reducing nitrate leaching and soil erosion (Quemada et al., 2020). And all of them are key factors for the sustainability of the systems. Moreover, the cover crop can offer the farmer many benefits and can be classified as:

• Cover crops, when their main purpose is to control soil erosion. They are widely used on slopes or covering streets in sloping woody crops, having been used with success especially in olive groves and vineyards.

• Green manures, when their main purpose is the contribution of nutrients and organic matter to the main crop by incorporating the vegetable residue into the soil. The most widely used species in this case are usually legumes, due to their ability to fix atmospheric nitrogen.

• Catch crops, when their main purpose is to retain certain elements of the soil in the plant biomass and thus, they are not lost by washing or runoff. The most used are usually those that avoid the washing of nitrates or those capable of absorbing heavy metals and / or organic compounds from phytosanitary products, thus avoiding the possible contamination of water and favoring the decontamination of soils.

However, cover crops management is frequently complicated, and farmers are not clear about which species/variety is the one that best suits their specific objectives (Ramírez-García et al., 2015). Because of that it is necessary further information about the specific growth characteristics and the biomass residue quality of different species and mixtures, to ensure an optimal cover crop selection by the farmers for nutrient recycling, soil quality improvement or soil carbon sequestration.

Proximal and remote sensing for supporting sustainability in cropping systems

Proximal and remote sensing, may have a relevant role in both, characterizing species/landraces to facilitate selection and collecting helpful information for improving nutrient and water management. Particularly, in the case of N several studies have shown that a good strategy to increase the efficiency of N use is to limit the application of N fertilizer in pre-sowing and apply it in covers that coincide with the maximum demand of the crop. At this time, the crop can be used as an indicator of N needs to adjust fertilization and to identify the contribution of the residual N to the crop requirements (Raya-Sereno et al., 2021). The N status can be estimated in the field with optical clamps, proximal sensors or field spectroradiometers that register the spectral crop signature. Additionally, thermal cameras can be used to identify the tolerance of cultivars to water stress (Leinonen et al. 2006) and the joint use of spectral and thermal cameras has highlighted the importance of the interaction of water and nutritional stresses (Pancorbo et al., 2021).

The use of remote sensing to obtain spectral signatures has contributed to make more efficient the screening and breeding of cultivars. Spectral reflectance is associated with specific plant characteristics and has been used with success in selection of wheat cultivars (Silva-Perez et al.

2018).To the best of our knowledge, these techniques have not been used in legume comparison, so this project is an opportunity to evaluate the capacity of optical sensors to distinguish among the performance of legume landraces.
The use of remote sensors to estimate crop nutritional and water status has shown a large potential for improving resource management, and it is the base for variable rate application of fertilizers (Diacono et al. 2013) and water (Lamm et al. 2019) that might allow increasing N and water use efficiency. Another relevant issue related to this project is remote sensing monitoring of soil cover by green or dead vegetation (Zheng et al. 2014). This coverage allows to compare the establishment of the cover crops and to adjust the improvement of the soil properties by the mulching of the residues. Soil cover reduces erosion and runoff, and it is also relevant to estimate soil C sequestration (Delgado, 2010), because of that is a key variable in models that predict the overall impact of agricultural systems (Galloza et al., 2013).

Hypothesis and objectives

The main hypothesis of this project is that the use of sensors may contribute to the introduction of legumes into Mediterranean cropping systems by improving characterization and breeding of pulse legumes and cover crops, and by better estimating the effect on the nutritional status and fertilizer savings of the subsequent cash crop.

Therefore, the main objectives of this project are:

- To evaluate the potential of sensor technology to select the most appropriate cultivars in screening experiments of legumes and wheat, particularly based on their adaptation to drought, soil coverage, biomass, and N accumulation.
- To determine the effect of the precedent crop (legume or grass) on wheat yield, fertilizer savings, and soil properties in large scale field studies accounting for spatial variability.

Relevant methodological aspects

Field experiment located in Alcala (Madrid) in which crop (biomass, N concentration, yield) and soil (C and N content, water content and physical measurements) determinations are conducted.
Application of hyperspectral, thermal and proximal sensors. Acquisition of satellite and UAV imagery.
Use of radiative model inversion and geospatial statistics.