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Original article

Intercropping maize and common bean enhances microbial carbon and nitrogen availability in low phosphorus soil under Mediterranean conditions

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A B S T R A C T

The beneficial effect of intercropping system under low phosphorus (P) conditions has already been reported in previous works. The aim of this study was to test the hypothesis that intercropping (common bean - maize) in P-deficient soil can enhance the carbon (C) and nitrogen (N) stocks from the microbial biomass (MB). The field experiment was conducted in Setif province in a northern Algerian agro-ecosystem with a Mediterranean climate. The nodule N storage in intercropped common bean was 60% higher than for sole crops and was highest in a P-deficient soil in the second year. The carbon stock from the microbial biomass of the soil (MBC) was higher with intercropping than for sole crops and fallow and was even higher in P-deficient (23%) soils as compared to P sufficient (17%) conditions. There was a strong correlation between C stock from nodule (NC) and MBC stock for intercropping in either P-deficient ($r^2 = 0.80^{***}$; $p < 0.001$) or P-sufficient soils ($r^2 = 0.69^{**}$; $p < 0.01$). P-deficient conditions gave the highest total soil respiration (1.68 g C-CO_2 m^{-2} $days^{-1}$) and the lowest MB C:N ratio (10.3 and 12.2 for common bean and maize, respectively) in intercrops system. This study showed that, in a P-deficient soil, intercropping is a good solution for increasing the rhizosphere MB through C and N partitioning between root nodules and rhizosphere microbial community, which is responsible for improving soil fertility and recycle mineral elements.

1. Introduction

A high soil quality improves agroecosystem services and sustains biological productivity which promotes plant growth and increases bioavailability of essential nutrients [1,2]. Species diversity has a beneficial effect through both functional complementarity and facilitation between plants which improves productivity as well as increases C and N stocks in the soil, the microbial biomass and the crop residues [3,4]. High C and N stocks in the soil are correlated with soil productivity. The soil organic matter (SOM) stock is a key biological factor and is one of the biological and chemical indicators that need to be evaluated in a soil fertility analysis [5]. In Algeria, the restoration of soils with low SOM has become a strategic necessity for food security, given the current economic situation [2,7].

Most studies on legume-cereal intercropping system have shown the efficient use of environmental resources by stimulating plant growth and yield in calcareous and P-deficient soils [2,8,9], compared with fallow-cereal rotation practice. The legumes could increase the availability of nutrients such as N [10] and P [11] in the rhizosphere of the intercropped cereals, improving grain yield, nutrient uptake and efficiency in use of rhizobial symbiosis (EUR), especially in low P conditions [2]. Intercropping can also improve growth and nutrient use efficiency through the stimulation of biological N_2 fixation by nodules of the intercropped legumes [12].

Recent studies suggest that N storage in legume-cereal intercropping is greater as a result of a higher EURS in a P-deficient soil than in a P-sufficient soil [2]. Changes in the C:N ratio of soil microorganisms (fungi and bacteria) have also been attributed to the relative demand of soil microbes for C and N [20]. These changes

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may have a major effect on N and C cycling.

Despite extensive literature on intercropping, little information is available on the effects of cereal-legume intercropping on microbial mediated processes and the relationship between intercropping and biological N_2 fixation by the legumes. Microbial biomass (MB) is one of the most important biological indicators for monitoring environmental change. It is also considered as important for planning appropriate land use and for the management of agriculture practices [1]. The carbon (MBC), nitrogen (MBN) and phosphorous (MBP) stock from the microbial biomass of the soil depends on the composition and structure of the microbial community [13], the growth stage of microorganisms and the environmental conditions [14]. In the rhizosphere, microorganisms assimilating C from rhizodeposits need P to satisfy their growth requirements and may, therefore, compete with plants for soil P. However, it has also been suggested that MBP is another pool of soil P that is potentially available to plants through the decomposition of dead microbial cells [13]. The MB pool can be a substantial source of available nutrients, such as C, N and P, for plant growth [1,16]. Furthermore, soil can be managed to improve either MBC or MBN stock by introducing crop management practices such as intercropping of cereals and legumes in agroecosystems [1,15].

Recent studies have reported an increase in microbial activity with higher SOM and MBC stock in intercropping systems than in corresponding sole cropping systems [17]. Tang et al. [16] observed a significant increase in MBC and MBP stock in the rhizosphere of intercropped legumes in a P-deficient soil.

In order to ensure food security in Algeria with the current economic crisis and declining oil prices, the development and intensification of local farming practices has become a strategic necessity. However, most northern Algerian soils are alkaline (pH varying from 7.5 to 8.5) [42], which is considered to be a limiting factor for the growth and nodulation of legumes [7]. In addition, fallow-cereals rotation is the most common system in Algeria for crop production [2]. There are two types of fallows in Algeria, one that is used to control weeds, store water and weakly enrich the soil with nutrients. However in the second fallow type; the soils were only plowed without any treatment such as fertilizer and irrigation. The latter is the most used for ecological intensification of agriculture in Algeria. In both cases, this practice is not profitable and does not allow either to satisfy the needs of the Algerian population or to ensure a good restoration of the fertility of the Algerian soils. This deprives the country's economy from freeing itself from dependence on food imports [42,45]. Finding solutions for the Algerian soil problems to replace fallow systems by more profitable agricultural practices is, therefore, currently a major concern.

The effects of intercropping on agroecosystem productivity and on C and N storage have been well documented for both the short-term and the long-term [1,16,17]. The C input into the soil through root residues, for both legumes and cereals, has been shown to be higher in intercropping than in monoculture systems [18,19]. Among possible interspecific interactions (complementarity and facilitation) between intercropped cereals and legumes; little information is available in the literature on the effect of this intercropping on changes in MBC:N ratio, soil respiration and nodule C (NC) and N (NN) stocks sequestered by root nodules.

A previous study reported that intercropping common bean and maize might be an alternative agronomical practice that is currently rarely used in north-east Algerian agroecosystems under low P conditions [2,11]. In the studies reported here, our first objective was to study, under P-deficient and P-sufficient conditions, the effects of intercropping common bean with maize on i) nodule C and N sequestration, ii) C and N stocks from the microbial biomass of the soil and iii) soil respiration. Our second objective was to attempt to explain the links between these effects.

2. Material and methods

2.1. Experimental sites and field plot design

The study was performed in 2012 and 2013 at the same two experimental sites (P-deficient) S1 (35°58, 11′N and 5°14, 90′E) and (P-sufficient) S2 (35°53, 37′N and 5°37, 01′E) as in our previous study [2]. These sites are located in the Setif agroecosystem (300 km east of Algiers) where maize and common bean are widely cultivated as intercrops. The previous study confirmed that these sites have very different soil P availability and EURS [2]. The soil physical and chemical properties for the P-deficient and P-sufficient sites were determined by standard sampling of the top layer (0–30 cm) at the sowing stage during the 2012 growing season. There were no significant differences for clay, loam and sand content between the two study sites. However, the chemical properties (total N, total P and bioavailable P) of the sites had been significantly affected by the land management. The P-deficient site had lower levels of N (0.7 g kg^{-1}) and P (total P: 71,7 ppm; Olsen-P:4.6 ppm) than the P-sufficient site (N:1.9 g kg^{-1};total P: 187.5 ppm and Olsen-P: 19.4 ppm). The $CaCO_3$ content in both sites varied from 22.5% to 25% with a relatively high pH of 8.3 in P-deficient and 7.7 in P-sufficient sites, respectively.

The study was carried out with one common bean cultivar (*Phaseolus vulgaris* cv. El Djadida) and one maize cultivar (*Zea mays* cv. Filou) which are the most common cultivars grown by farmers in Algerian agroecosystems. The experimental design was a split plot with four replicates. Each sub-plot was cultivated with common bean as sole crop, maize as sole crop, maize-common bean intercrop and fallow (uncultivated plot) (4 cropping systems x 4 replicates). The planting density was that commonly used by farmers: 24 plants m^{-2} for common bean and 15 plants m^{-2} for maize as sole crops, and 12 plant m^{-2} for each species intercropped. All crop management such as sowing, amendment and irrigation was carried out by farmers. The soil in the fallow plot was ploughed and left unplanted according to local farming practices (with the same interventions which are applied in crop treatment such as irrigation and weeding). The soils from the fallow were taken as a control as well as from the rhizosphere of each species in crop system. While the same type of fallow treatments was practiced in the experiment field according to farmers' practices.

2.2. Nodule harvest and rhizosphere soil sampling

Seventy days after sowing, corresponding to the full flowering stage, soil samples were taken from the rhizosphere of each species and the fallow plot. The rhizospheres of each of the maize and common bean roots were bulked for each replicate in all cropping systems. The rhizosphere samples were then stored at 4 °C for 72 h before analysis. The nodules were separated from the common bean roots, dried and weighed separately.

For the soil samples during first growing season (2012), the total P concentration was determined using the malachite green method after digestion by nitric and perchloric acid [21]. The soil P availability was determined by $NaHCO_3$ extraction (Olsen method, [22]) and the rhizosphere pH was measured in soil suspended in purified water with a soil: water ratio of 1: 2.5 [23]. The calcium carbonate ($CaCO_3$) concentration was determined in the laboratory by measuring the volume of CO_2 evolved using the Horton and Newson method.