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The Effects of Legume Crops (Pea and Faba Bean) on Soil Nutrients Availability and Yield Parameters of Subsequent Cabbage Crops under Organic Production Conditions

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Abstract: Three equal field plots were cultivated with respectively wheat, field pea and faba bean. The common conventional production technology, including the use of chemical fertilizers was applied in wheat, but no fertilizers at all were used in faba bean and field pea plots. After legume harvesting, forty day old broccoli and cauliflower seedlings were transplanted to each of them according to three replications randomized block design. The transplanting was conducted at equal planting density, and common organic production practices were applied in entire production cycle. The legume crops improved soil fertility by increasing total soil N (Nitrogen) and improving P (Phosphorus) and K (Potassium) availability to the subsequent crops. As a result, an enhanced vegetative growth, improved curd setting and increased average curd weight was found in broccoli and cauliflower. However, there were significant differences between legume crops themselves regarding the proved benefits to the subsequent crops, confirming a clear advantage of faba bean versus field pea. A significantly higher above ground biomass was recorded in cauliflower plants followed faba bean, compared with field pea and wheat, but no difference was found regarding the biomass production in broccoli. The higher percentage of plants set curds (either broccoli or cauliflower) was obtained in the variants followed faba bean and then field pea. The same was true regarding total curd yield and the average curd weight for both: broccoli and cauliflower.

Key words: Total N (Nitrogen), extractable P (Phosphorus), extractable K (Potassium), average curd weight, curd yield.

1. Introduction

Legumes are a large group of angiospermal plants found in all continents capable of growing in very diverse aquatic and terrestrial environments, under different edaphic and climatic conditions [1]. During centuries of selection and breeding, thousands of legume cultivars were developed and diversified for different purposes [2]. Among them, the grain legumes, field pea (*Pisum sativum* L.) and faba bean (*Vicia faba* L.) are worldwide commonly grown as protein source for food and feed, while at the same time they offer other ecosystem services [3]. Growing legumes would improve soil quality by enhance the N-supplying power of soils, increase the soil reserves of organic matter, stimulate soil biological activity, improve soil structure, increase soil aeration, improve soil water-holding capacity and make the soil easier to till [4].

BNF (Biological Nitrogen Fixation) is the distinguishing feature of a legume in a cropping system. Most legume species are able to form a symbiosis with alpha or beta-proteobacteria, collectively called rhizobia, that use solar energy captured by the plant to break the bond in inert atmospheric dinitrogen and form reactive N species [5]. Therefore, including grain legumes in crop rotation schemes reduces the need of N (Nitrogen) fertilizer, because they are able to grow with no or

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minimal fertilizer N. And in addition, the nonlegume crops following grain legumes have reduced N requirements. The deposition of legume N is constituted by root exudates, sloughed cells and root nodules during plant growth, and the decomposition and mineralization of the complete root system, senescent leaves that are dropped as legume crops reaches maturity, and the shoot residues remaining after grain harvest [3].

Although legume N credit was found low (~30 $kg·N·ha^{-1}$), the N fertilizer replacement value was 51 to 77 $kg·N·ha^{-1}$ for corn and up to 37 $kg·N·ha^{-1}$ for wheat, depending on the preceding legume crop [6]. This suggests that indirect effects related to improved soil properties impacts positively the subsequent crop yield and N nutrition. Including grain legumes in crop rotations includes other benefits such as breaking disease and pest cycles of subsequent crops, improving soil structure and improving biological soil health through increased microbial biomass, diversity and activity [7].

Distinct differences exist between the legume species in their capacity for N_2 fixation. While for example, faba bean has a slower uptake of the mineral N than pea until full bloom; it is able to compensate the lower fertilizer and soil N uptake by a greater N_2 fixation [3]. Furthermore, due to their indeterminate growth habit faba beans continues assimilating N for a longer period than pea, reaching about 315 $kg·N·ha^{-1}$ after 110 days [8].

The legume crops do also improve P (Phosphorus) and K (Potassium) availability to the subsequent crop, leading to better growth in soils where P and K availability are limiting factor. The mechanisms that different grain legume crops possess for enhancing P uptake are different, including root exudates and high biomass allocation to roots [9, 10]. Among them, faba bean showed superior P uptake and a greater P effect on the subsequently grown crop [11].

Considering those potential direct and indirect benefits of including a legume crop in vegetable crops rotations, an experiment was conducted to compare the effects of field pea and faba bean versus the winter wheat on soil N, P and K availability to the following crops and yield parameters of subsequent cruciferae vegetables (broccoli and cauliflower) under common organic growing conditions.

2. Materials and Methods

2.1 Experiment Conditions and Plant Material

The experiment was conducted in Lushnja (40.942° N, 19.699° E), Albania, during the period November 2014 to November 2015. The experimental field was divided in three equal plots (600 m^2, each) and seeded in November 12, 2014 with respectively field pea (*Pisum sativum* L.), faba bean (*Vicia faba* L.) and wheat (*Triticum aestivum* L.). Both, pea and faba bean were sown in equally distributed rows, 0.6 m apart from each other. Following the full plant germination, the distance between plants in the rows was settled to 0.05 m. No chemical fertilizers and pesticides were applied, while to fulfill the water demands of both of them. Several irrigations were conducted during the period of pod setting and seed development through a sprinkler irrigation system. The same time, the common commercial planting distances; equally distributed rows, 15 cm apart, and the common local production technology, including the use of chemical fertilizers (50 $kg·ha^{-1}$ DAP as basic dressing and two additional fertilization, 200 $kg·ha^{-1}$ ammonium nitrate each) were provided in the wheat field plot. The harvesting of all three crops was conduct at full seed's maturity stage of each one during the second half of June 2015.

Immediately, after wheat and legume crops were harvested, common soil preparation practices were implemented to prepare it for cauliflower and broccoli transplanting. For that purpose, graded seeds of cauliflower (cv. Flamengo F1, Bejo Zaden b.v., Warmenhuizen, The Netherlands) and broccoli (cv. Batavia F1, Bejo Zaden b.v., Warmenhuizen, The Netherlands) were sown in foam trays. Each tray contained 120 plugs, 20 cm^3 each, filled with peat compost (Klasmann Potground H; Klasmann-Deliman, Deutschland). After sowing, the trays were transferred into a plastic greenhouse and kept in there till the day of transplanting in open field. Frequent irrigations were applied through an overhead sprinkler system, but no fertilizers were applied during the entire nursery period.

Following soil preparation, 40 day old cauliflower and broccoli seedlings were transplanted to the field in July 25, 2015. An equal number of seedlings of each of them were transplanted at a common planting density (0.6 m × 0.3 m) at each replication. Common organic production practices were applied (weeding, hoeing) and several sprinkler irrigations were applied, immediately after transplanting until autumn rains started, but no fertilizers were applied throughout the whole plant' growing cycle of both, broccoli and cauliflower.

2.2 Chemical Analyses

An homogenized soil sample as representative of the whole experimental field was received in November 2014, before legume and wheat to be sown, and three separate soil samples to each individual plot of pea, faba bean and wheat were received before legume flowering period (end of April 2015) and after legume harvesting (July 2015). pH (water), total N and NO_3-N (Khejldahl), extractable P (Mehlich 3) and extractable K (Mehlich 3) were analyzed for each soil sample. As well, one month after transplanting, leaf samples were randomly collected from both cauliflower and broccoli plants transplanted to each previous field blocks (pea, faba bean and wheat) and chemical analyses for the total amount of N, P and K were conducted.

2.3 Yield Parameters

The harvesting of fully developed curds was conducted during November 2015, after the growth of each individual curds was ended. Several harvestings were conducted, from the end of October 2015 to end of November 2015, till entire production was collected. By the end of harvesting, the ratios of plants had been set, and curds versus the total number of plants of each experimental plot were calculated. The harvested curds were individually weighted and recorded. The total yield for each experimental plot was counted as the sum of individual harvested plants. At the peak of harvesting period, 10 randomly selected plants of each plot, were cut off at the root neck and then divided into the vegetative part and the curd. The fresh weights of the vegetative parts and curd were individually weighted and recorded, and afterwards the ratio of curd weight versus the total plant weight was calculated.

2.4 Statistics

The experimental design was a three replications randomized block. Differences in total plant biomass, yield, average curd weight, percentage of plants set curds and the ration of curd weight to total plant biomass were tested between by two ways ANOVA, using the PC program StatPlus 2009 (Analyst Soft Inc., Walnut, CA, USA). Each significant ANOVA result ($p < 0.05$) was followed by Tukey-Kramer test at $p < 0.05$ as post-hoc test to compare pair wise means within and among treatments. Values given throughout the text are means ± SD.

3. Results and Discussion

Till the start of flowering, no significant differences were found regarding total soil N content either between wheat with each legume crop or between the legume crops themselves. Though, in fact, there was a slight increase of total N content in both; faba bean and field pea plots, the differences with the wheat plot were not statistically significant (Table 1). Indeed, although like the other legumes, field pea and faba bean can symbiotically fix atmospheric N_2, they will initially depend on seed N sources and mineral N acquisition during seedling emergence until nodules are established [3]. Considering that the rate of atmospheric N fixation in legume crops is low in the early growth stages and reaches its maximum value between early flowering and early seed-filling [12]. No significant increase in soil N content should be expected up to this stage of plant development. Furthermore, it is a well-known fact that the legume crops can accumulate N both from soil and the atmosphere and the relative contribution from each source to satisfying theirs. N requirements for growth will be heavily influenced by the concentrations of available soil mineral N in the rooting zone [13]. Therefore, high levels of mineral N will inhibit both the formation and N fixation activity of nodules [3, 14]. Thus, the relatively high N soil level before the start of experiment (Table 1) was another reason of low legume N fixation activity till the start of flowering.

Different from the start of flowering, significant differences regarding total soil N content were found between the legume crops and wheat after harvesting. Total N content was significantly reduced compared with the pre-sowing period in the wheat plot, but contrary with that, total soil N content was significantly higher in the field pea and faba bean plots (Table 1). Clearly, this result confirms the widely accepted role of legume crops regarding N soil enrichment capability.

According to previous reports [7, 15], although much of the N_2 fixed by the legume crops is usually removed at harvest in high-protein seed and thus the net residual contributions of fixed N to agricultural soils after the harvest of legume grain may be relatively small, it plays an important role in enriching the pools of soil N for non-N-fixing crops grown after the legumes. Therefore, the inclusion of legumes in a cropping sequence generally improves the productivity of following crops. The contribution of legume crops to the increase of total N soil content can be derived from unused ("spared") soil mineral N and rhizodeposits of N remaining after crop growth, or N mineralized from above-ground organic residues and the nodulated roots following grain harvest [3].

Significant differences were as well found between the legume crops themselves regarding the total soil N content after crop harvesting (Table 1). Indeed, total N in faba bean plot reached the highest concentration (2,238 $mg \cdot kg^{-1}$), which was also significantly higher than the respective N concentration in the field pea plot (1,946 $mg \cdot kg^{-1}$). Previous reports confirmed our results. According to Jensen et al. [12], faba bean has the highest average reliance on N_2 fixation for growth of the major cool season grain legumes, and the N benefit for following crops is calculated up to 100-200 $kg \cdot N \cdot ha^{-1}$.

Though non statistically significant, soil extractable P content in the field pea plot at the start of flowering period was slightly lower compared with soil P content before sowing (61.9 versus 69.9 $mg \cdot kg^{-1}$). Since, among many environmental factors (temperature, water content, pH and N concentration) the biological nitrogen fixation process in legume crops is also affected by plant nutritional status such as P (Phosphorus) level which controls nodule growth and nitrogenase activity [12] a high P and K use in this

Table 1 Soil chemical analyses before sowing, at the flowering time and after the harvesting of wheat and the legume crops. N ($mg \cdot kg^{-1}$, by Khejldahl method), extractable P ($mg \cdot kg^{-1}$, by Mehlich 3 method), extractable K ($mg \cdot kg^{-1}$, by Mehlich 3 method). Mean values ± SE, different letters within each row indicate statistical differences at $p < 0.05$.

Parameters	Before sowing	Start of flowering			After harvesting		
		Wheat	Pea	Faba bean	Wheat	Pea	Faba bean
pH	8.15 ± 0.1	8.22 ± 0.1	8.31 ± 0.1	8.24 ± 0.1	8.20 ± 0.1	8.41 ± 0.1	8.36 ± 0.1
N-total	1,454 ± 130c	1,422 ± 130c	1,516 ± 143c	1,477 ± 120c	1,050 ± 90d	1,946 ± 136b	2,338 ± 174a
P	69.9 ± 6b	53.0 ± 5c	61.9 ± 6bc	76.2 ± 6a	49.2 ± 5c	65.3 ± 5b	89.2 ± 7a
K	318.51 ± 27a	296.5 ± 22a	326.5 ± 24a	341.9 ± 30a	180.0 ± 16c	205.7 ± 20c	269.5 ± 24b

stage of plant development is expected. However, at the same period soil P content in the wheat plot was much less (only 54 mg·kg^{-1}) and significantly smaller compared with the pre sowing period (Table 1). Interestingly, a significantly higher extractable P content was found in case of faba bean. Its differences with the pre sowing period and the respective extractable P content in pea and wheat plots prior to flowering were statistically significant, and further increased (89, 2 mg·kg^{-1}) after crop harvesting (Table 1).

An explanation for the highest extractable P content in legume plots is provided by Nuruzzaman et al. [11]. According to them, the carboxylate-exuding legumes, such as field pea, exude particularly large amounts of organic acids into the rhizosphere, especially as a response to P-deficiency. Under such conditions, these exudates can help mobilise P from soil-P pools, which are unavailable to plants that do not possess this adaptation. Anyway, there are differences among legume crops regarding the mechanisms of nutrient acquisition from the soil. According to Nuruzzaman et al. [11], the high P content of faba bean plants is likely due to its large root system rather than enhanced P uptake through a specialized mechanism. Thus, its positive effect on increased soil P concentration after harvesting is more closely related to the mineralization of P-rich plant residues rather than to residual effects of the root exudates on soil chemistry.

Authors did not found any difference between the legume crops and wheat regarding soil extractable K till the beginning of legume flowering. Indeed, compared with the pre-sowing period a slight decrease of extractable K was found in wheat plot, but not statistically significant. At the same time, a slight increase of extractable K was found in field pea and faba bean plots, but not statistically significant. On the contrary, the concentration of extractable soil K after legume harvesting was significantly reduced compared with the pre-sowing period suggesting the great potassium demand of legume crops during the grain filling period. However, a significantly higher K content was found in faba bean plot compared with wheat and field pea, which like in P case should be explained with its deeper and stronger root system which allows faba bean to exploit a larger soil volume and further enrich the upper soil layer thanks to the mineralization of the organic matter of its root system.

Authors found that the higher total soil N content after harvesting of the legume crops was reflected in a higher leaf N concentration of the following cabbage crops. One month after transplanting, N-NO_3 and total N content in the leaves of cauliflower and broccoli followed field pea and faba bean, were significantly higher than the respective content in cauliflower and broccoli plants followed wheat (Table 2). Further, that was reflected in significant differences regarding the plant's biomass and yield parameters in both cabbage crops.

Authors' results fit well with the conclusion of N'Dayegamiye et al. [6] that including legume crops in the rotation can provide a direct N contribution and

Table 2 N-NO_3 and N-total content (mg/kg) in the leaves of broccoli and cauliflower seedlings one month after transplanting following wheat, pea and faba bean. Mean values ± SE, different letters within each row indicate statistical differences at $p < 0.05$. Capital letters indicate differences among cauliflower experimental plots and small letters indicate differences among broccoli experimental plots.

Preceding crops	Subsequent crops	N-NO_3 (mg/kg)	N-total (mg/kg)
Wheat	Cauliflower	2,355.2 ± 200 C	14,768.6 ± 1110 B
	Broccoli	2,042.1 ± 180 c	14,624.3 ± 1200 c
Pea	Cauliflower	3,423.2 ± 300 B	14,018.2 ± 1350 B
	Broccoli	2,844.6 ± 250 b	17,241.7 ± 1440 b
Faba bean	Cauliflower	4,445.4 ± 300 A	25,998.3 ± 2000 A
	Broccoli	5,631.8 ± 400 a	22,588.3 ± 2000 a

Table 3 Total biomass and curd yield parameters of broccoli and cauliflower crops following wheat, pea and faba bean. Mean values ± SE, different letters within each row indicate statistical differences at p < 0.05. Capital letters indicate differences among cauliflower experimental plots and small letters indicate differences among broccoli experimental plots.

Preceding crop	Subsequent crop	Total biomass ($gr \cdot plant^{-1}$)	Yield (kg/variant)	Average curd weight (gr/head)	Curd setting (%)	Curd/Total biomass ratio (%)
Faba bean	Broccoli	611.5 ± 246.5	19.6 ± 3.5a	138 ± 64	0.90 ± 0.06a	0.28 ± 0.03
	Cauliflower	1360.5 ± 374A	72.9 ± 9.1A	527 ± 136A	0.90 ± 0.04A	0.39 ± 0.08
Field pea	Broccoli	482.3 ± 160.7	13.4 ± 2.5b	84 ± 30	0.88 ± 0.08a	0.17 ± 0.03
	Cauliflower	642.5 ± 221.1B	37.3 ± 5.9B	233 ± 118B	0.90 ± 0.04A	0.35 ± 0.09
Wheat	Broccoli	448.3 ± 117.0	8.2 ± 2.3c	79 ± 25	0.72 ± 0.11b	0.18 ± 0.04
	Cauliflower	553.8 ± 172.6B	28.5 ± 4.8B	214 ± 94B	0.76 ± 0.06B	0.37 ± 0.09
Significance						
Precrop (Pc)		***	***	***	*	*
Crop (C)		***	***	***	ns	***
Pc × C		***	*	***	ns	ns

indirect benefits to crops by improving soil fertility. Compared to wheat, the legume crops provided a significantly higher biomass and a higher yield to the subsequent cabbage crops (Table 3). Anyway, there were significant differences between legume crops, themselves. It was faba bean that provided the highest vegetative growth of both, broccoli and cauliflower. The total biomass ($gr \cdot plant^{-1}$) of cauliflower plants grown after faba bean was almost twice higher than the respective cauliflower plants, which are grown after wheat and field pea (Table 3). Yet, no differences were found between the wheat and field pea regarding the total plant biomass of subsequent crops, either broccoli or cauliflower (Table 3).

The differences between the legume crops (field pea and faba bean) and wheat, were more distinguished regarding the edible part (curd) production. Head and curd formation and development of cabbage crops is a complicated and very sensitive process [16], and there are reports that confirm that curd initiation and development of broccoli and cauliflower are influenced by P availability to the plants [17, 18]. Authors also found a good correlation of extractable P content in the soil and the yield of subsequent crops (Tables 1 and 3). Following the highest extractable soil P after legume harvesting (Table 1), the highest curd production in both broccoli and cauliflower were received in the variants planted after faba bean (Table 3). The differences either with field pea, or wheat plots were statistically significant (Table 3).

As well, a significantly higher percentage of plants set curds were found in broccoli and cauliflower variants grown after legume crops, versus the respective variants grown after wheat. Though, no differences were found between the legume crops and wheat regarding the average curd weight in broccoli (Table 3). The average cauliflower curd weight in the variants grown after faba bean was twice higher than the respective curd weight of plants grown after wheat and field pea. However, no differences were found regarding the ratio of curd weight to total plant biomass, which in broccoli and cauliflower seems unlikely to be influenced by the preceding crop (Table 3).

4. Conclusion

The legume crops improve soil fertility by increasing soil total N and improving P and K availability to the subsequent crops. Therefore, they enhance vegetative growth, improve curd setting and increase average curd weight in broccoli and cauliflower. However, there are significant differences between legume crops themselves regarding the expected benefits to the subsequent crops proving a clear advantage of faba bean versus field pea.

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