Archives of Agronomy and Soil Science, 2015
Vol. 61, No. 4, 461–473, http://dx.doi.org/10.1080/03650340.2014.943667

Grain legume effects on soil nitrogen mineralization potential and wheat productivity in a Mediterranean environment

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(*Received 20 February 2014; accepted 7 July 2014*)

The objective of this work was to provide evidence on the effects of faba bean (*Vicia faba* L.) and chickpea (*Cicer arietinum* L.) on the dynamics of soil N availability and yield parameters of wheat (*Triticum turgidum* L. var. *durum*) in a legume–wheat rotation in comparison with the effects of the more extensively studied common vetch (*Vicia sativa* L.). Soil samples were taken from field plots just before wheat sowing and incubated in the laboratory to assess N mineralization potential, soil respiration and N immobilization after incorporation of legume residues. Soil after vetch cultivation showed the highest residual N and mineralization potential (120 mg N kg^{-1} soil), the greatest CO_2 release and the smallest N immobilization. Smaller mineral N release (80 mg N kg^{-1} soil) was shown by soil after faba bean cultivation, which, however, would be capable to support an average wheat production without fertilization. Soil after chickpea and wheat cultivation manifested no differences in residual N and mineralization or immobilization potential. Laboratory results were well correlated with grain yield and N uptake during the second season of rotation in the field. All legumes resulted in significant yield surpluses and provided N credit to the following unfertilized wheat.

Keywords: nitrogen mineralization potential; legume–cereal rotation; nitrogen benefit; faba bean; chickpea

Introduction

Annual legumes are principally used as a substitute of commercial N fertilizers or to restrain soil degradation that inevitably accompanies intensive agriculture. In Mediterranean climates, N fertilization from organic sources (e.g. from legumes cultures) is more preferred than inorganic fertilizer application due to uncertain weather conditions (Campbell et al. 1991). Additionally, it has extensively been shown that legume integration in rotation systems has the potential to enhance yields of subsequent crops (Papastylianou 1987; Ryan et al. 2008; Peoples et al. 2009).

The potential benefits achieved from the presence of legumes in rotation systems include reduction in disease and weed occurrence, pest damage, improved soil structure, greater provision of nutrients and enhanced soil biological activity (Peoples & Herridge 1990; Bellido et al. 1996). Some of these benefits can be observed from the first season while others occur in the long-term (Rego & Seeling 1996; Papastylianou 2007).

Among these, N benefits, also known as N effect or N credit, are probably the most significant and certainly the most widely studied. Despite that a great part of the atmospheric N_2 captured by symbiotic root bacteria ends up in grain (especially in grain

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legumes) and is ultimately removed by grain harvesting, nitrogen benefits can still be obtained by rotation systems that include legumes (Pate et al. 1988). The investigation of the dynamics of organic N pools in soil and eventual balances between inputs of N through symbiotic fixation and removal of N by grain harvesting requires long-term studies (Rego & Seeling 1996).

Even though the long-term agronomic benefits of the symbiotic N_2 fixation are still uncertain, immediate positive effects are frequently observed on cereal crops that follow legumes in rotation systems. There is already a lot of evidence suggesting that these effects are associated with improved supplies of soil available N (Biederbeck et al. 1996).

One of the mechanisms explaining the increased supply of available N to crops following legumes is N-sparing. Since most of their N requirement is met by N_2 fixation, legumes utilize less of the available soil N than cereals, thereby 'sparing' or 'conserving' inorganic N for the intercrop or following crop (Chalk et al. 1993; Herridge et al. 1995). A more conservative use of soil N by legumes is, however, not universal and seems to depend on species or even genotype and seasonal conditions (Unkovich & Pate 2000). Evidence of N-sparing is provided when available soil N is depleted with a smaller rate compared with a non-fixing crop (Herridge et al. 1995), or when a significant fraction inbuilt tissue N is shown to be provided by fixed N (Moolecki 2000). It is emphasized though that under Mediterranean conditions spared N may not become available to the cereal crop which is seeded almost six months after legume harvesting. From this point of view the safest measurement to assess the carry over effect of legume is not spared N but residual N on the following season start.

The major benefits of the rotation system are related to the rate of decomposition and associated N release from legume residues since their stems and leaves are easily decomposable by soil microorganisms. They usually have low C/N ratio and low lignin content, immobilize soil mineral N to a lesser extent and enter the net mineralization phase faster than cereal residues (Green & Blackmer 1995; Fosu et al. 2007).

The total N content in harvested above-ground parts of a crop has quite extensively been used as an estimate of soil mineral N supply potential (e.g. Agegnehu et al. 2014). In legume–cereal rotations in particular, the magnitude of net nitrogen mineralization is assessed by the overall uptake of the cereal crop in unfertilized plots during the growing season plus mineral N in the root zone at harvest minus mineral N before sowing (Stanford et al. 1973; Thicke et al. 1993). However, field conditions rarely allow net N release to reach the mineralization potential. Moreover, the amount of soil N taken up by plants is influenced not only by net N release but also by other processes, such as leaching or denitrification, which reduce the available N pool. Laboratory incubation experiments at optimum conditions thus provide an alternative approach to estimate the absolute value of soil N mineralization potential after legumes and ultimately a more accurate comparison between legume species (Wani et al. 1995).

The main rotation system in Cyprus (and other dry Mediterranean regions) is the vetch-cereal system (Papastylianou & Samios 1987). Vetch, which is usually incorporated in soil during flowering, has been proved to provide N to subsequent crop and also mitigate yield losses caused by pathogens and pests (Ryan et al. 2008). Winter grain legumes are seemingly less interest in adding external N to the system compared with forage legumes because a greater amount of fixed N is removed from the site in the grain at harvest (van Kessel & Hartley 2000). However, overall benefits from grain legumes can be significant (Bedard-Haughn et al. 2013) such as increase of producer income without compromising forage production, meet of food security demand by providing a cheap source of protein for human and animals and part of a more sustainable cropping system than cereal monoculture (Jensen et al. 2010).

The aim of this study was to (i) investigate the possible effects of two grain legumes (faba been and chickpea) and a forage legume (vetch) on wheat yield and N uptake as part of a legume–cereal rotation system, (ii) examine the benefit of wheat after legume cultivation due to residual N at sowing or soil N mineralization during the growth period and (iii) validate yield surpluses of wheat in legume–wheat rotation systems in field according to laboratory mineralization potential measurements of soils.

Materials and methods

Field experiment

Location and field characteristics

The field experiment was carried out in an experimental station of the Agricultural Research Institute (ARI) of Cyprus near the city of Paphos (34°44′ N, 32°29′ E).

This field had been used for wheat cultivation (*Triticum turgidum* L. var. *durum* cultivar Ourania) for at least four seasons prior to the start of the current experiment. It was being tilled once a year, before sowing, using a rotating harrow machine and mechanically harvested.

Some of the general soil characteristics, which were measured at the beginning of the field trials before laying out the plots, are shown in Table 1. The study site had a deep alluvial clayey soil with vertic characteristics and a relatively high organic matter content and general fertility compared with other soils in Cyprus. Soil in the study site is characterized as clayey (Vertic Luvisol), with $CaCO_3$ content of 13.5%, pH of 7.9 and organic matter content of 1.5% (Table 1).

Climate data

Table 2 shows precipitation and air temperature data for the two growing seasons of the experiment. Rainfall during the 1st season (legume crop cultivation) was 93% of the normal 30-season average for the area (404 mm), while the 2nd season (wheat cultivation) rainfall rose to 134% of the normal.

Table 1. Some of the physical and chemical properties of the soil in the experimental field.

Properties		
Organic matter	(%)	1.5
Total N	(%)	0.085
Mineral N	(mg kg^{-1})	5
Available P	(mg kg^{-1})	8.4
Exchangeable K	(cmol kg^{-1})	2.1
pH		7.85
Electrical conductivity	(mS cm^{-1})	0.17
$CaCO_3$	(%)	13.5
Sand	(%)	20
Silt	(%)	25
Clay	(%)	55
Bulk density	(g cm^{-3})	1

Table 2. Monthly precipitation and average maximum and average minimum temperatures during the two growing seasons of the experiment.

	Rainfall (mm)		Temperature (°C)			
	2010–2011	2011–2012	2010–2011		2011–2012	
			Average max	Average min	Average max	Average min
Oct	7.7	16.6	27.4	18.7	26.2	17.4
Nov	0.0	72.4	25.7	14.8	21.3	12.0
Dec	70.7	124.9	21.7	12.8	19.2	10.2
Jan	97.4	193.5	18.6	10.2	16.6	9.1
Feb	79.6	57.9	18.3	9.8	16.8	8.2
Mar	70.2	29.2	19.4	9.8	18.5	9.0
Apr	46.1	15.1	21.3	13.3	21.8	12.3
May	4.3	28.8	24.6	16.0	24.4	15.9
Total	376.0	538.0				

Experimental design

Two season legume–wheat rotation systems were established in small non-irrigated field plots. The experiment was set as a completely randomized design. During the first season of the rotation cycle, 3 m × 3 m plots separated by 2 m corridors were planted with three legume species and wheat (control) in three replications. At the end of this season, grain and harvested aboveground biomass and their respective N concentrations were estimated. Legume residues were returned to the original plots after weighing and sampling a small quantity for incubations.

During the second season of the rotation in the field all plots were cultivated with wheat. At the end of this season, grain, biomass and N yields were estimated and soil samples were taken again from all plots one day before harvesting to estimate mineral N content. Between seasons the field was fallow.

Crops

First season crops were common vetch (*Vicia sativa* L. var. Kimon), chickpea (*Cicer arietinum* L.), faba bean (*Vicia faba* L.) and wheat (*Triticum turgidum* L. var. *durum* cultivar Ourania). Seeding density (200 kg ha^{-1} for faba bean, 170 kg ha^{-1} for chickpea and 120 kg ha^{-1} for vetch and wheat), row spacing of 30 cm and application of insecticides during the growing period, represented usual farmers' practices.

Sowing and harvest dates

The field experiment started in December 2010 after cultivation with a rotavator and was harvested by hand in May 2011. The second season of the rotation cycle started late November 2011 and wheat crop was harvested at the beginning of June 2012.

Soil and plant analyses

Vegetative plant material and grains were ground prior to the determination of total organic nitrogen, which was carried out by the Kjeldahl digestion method (Allen et al.

1974). Water holding capacity (WHC) of the soil was estimated to assess the amount of water needed to bring soils to optimum moisture conditions for microbial activity during laboratory incubations. For the measurement of WHC, soil samples were placed in special constructed porous funnels and soaked in water for 24 h. The water tension was then standardized by applying a suction of 0.1 MPa. The moisture retention capacity was then determined as a percentage of oven dry soil (105°C for 24 hours).

Laboratory experiment

Soil sampling

Six months after harvesting first season crops, a little before second season soil cultivation and sowing of wheat in all plots, soil samples were taken for analysis and laboratory incubations.

Plant residues and two centimetres of soil were carefully removed from the surface and five subsamples of soil from each plot (2–10 cm soil depth layer) were taken using a scoop and mixed in a plastic bag. Samples were transferred to the laboratory, air-dried and passed through a 2-mm sieve.

Soil respiration

Twenty-four soil samples, two from each plot were incubated for 87 days to estimate microbial respiration. 75 g of soil contained in plastic pots were remoistened by adding water corresponding to 70% of the WHC of soils. Incubations were carried out in 2 L gas-tight jars kept in an incubation chamber at 25 ± 2°C. To maintain a vapour-saturated atmosphere inside the jars water was always kept at their bottom. Evolved CO_2 was captured in a vial containing 40 mL of 0.5 mol L^{-1} NaOH and the quantity of CO_2 absorbed in the alkali was determined by titration with 0.2 mol L^{-1} HCl (Pansu & Gautheyrou 2006). Statistical analysis of data was carried out based on variation between plots values, each one of which was the mean of the two sample replications of the plot.

Soil N mineralization potential

Soil samples were also used to estimate their N mineralization potential in controlled moisture and temperature conditions. Incubations of these samples was carried out in small plastic 50-ml containers filled either with 20 g of soil only or with 20 g of soil and 0.1 g of plant residue material. In order to reduce evaporation water losses, lots of 5–6 containers were enclosed in glass jars with air tight fittings, as the ones used for soil respiration determination, which were often being opened to replenish oxygen. Again, water added in containers corresponded to 70% of the WHC of soils, whereas throughout the incubation temperature was kept at 25 ± 2°C. The amount of mineral N in the soil samples was determined at regular intervals up to 134 days from the onset of incubation. Each time, three samples per treatment, one from each field plot, were removed from the incubation chamber.

Soil inorganic N (NH_4^+–N and NO_3^-–N) was extracted at each time point with 2N KCl. The whole content of the plastic containers used for incubations (20 g of soil) was used for extraction. Samples were shaken for 30 min, sieved through No. 2 Whatman filter paper and stored frozen. Inorganic N was determined in extracts by colorimetric methods. Nitrate determination involved reduction of nitrate to nitrite by a copper–cadmium column. The nitrite was then measured following reaction with a diazotizing reagent (sulphanilamide) and a coupling reagent (N-(1-naphthyl)-ethylenediamine dihydrochloride). The purple colour developed was measured at 550 nm. The estimation of NH_4^+–N was based on the emerald green colour formed when ammonia and sodium salicylate react in the presence of sodium hypochlorite at high pH. The colour reaction was catalysed by the presence of sodium nitroprusside.

Nitrogen mineralization data were fit using an iterative approach (Graphpad Software, Inc., San Diego, CA) to the following single compartment exponential model to determine potentially mineralizable N and mineralization rate constant (Stanford & Smith 1972) according to Equation (1):

$$N_t = N_{max}\left(1 - e^{-kt}\right) \tag{1}$$

where, N_t is the amount of N mineralized (mg N kg^{-1} dry soil) at time t, N_{max} the size of potentially mineralizable N (mg N kg^{-1}soil); the asymptote of the curve, k the rate constant (day^{-1}) and t the incubation time (days).

Statistical analysis

Comparisons of grain, residue yields and N concentrations between treatments were carried out using an analysis of variance (ANOVA) followed by Tukey's multiple comparison test (P < 0.05 – Graphpad Software, Inc., San Diego, CA). ANOVA was also used for statistical analysis of cumulative amounts of CO_2–C and mineral N released at the end of the laboratory incubations.

Results

Field experiment

Yield results of the first season of the rotation are shown in Table 3. Total aboveground plant biomass including grain and plant residue contained between 71 and 208 kg ha^{-1} of N. It is unknown how much of this N came from atmospheric N_2 fixation but soil itself can be assumed to have provided at least 71 kg N ha^{-1} as was the quantity found in aboveground biomass of wheat without fertilization. Most of biomass N was removed in seed, and specifically, 80% for wheat, 83% for chickpea and 85% for faba bean but only 58% for vetch.

The amount of N in residue that was left on the soil surface was greater for vetch followed by chickpea and almost three times smaller for faba bean (Table 3). These values do not include, though, litter production. At harvesting part of the leaves, particularly of faba bean, had already been fallen on soil surface as litter and has not been accounted. Some of the legume residue decomposed during the summer and autumn months that followed harvesting as a significantly smaller amount could be seen in late November during soil cultivation.

Wheat of the second rotation season yielded very differently depending on previous season crop. Grain and straw produce of wheat at each treatment is shown in Table 3. This Table shows also % N content of aboveground parts and total N removed from these parts (in kg ha^{-1}). Wheat following vetch grew bigger, removed more N and had greater N concentrations than wheat at the other treatments followed by faba bean and chickpea,

Table 3. Grain and residue yields (±SEM) of the first and second year of rotation. Nitrogen concentrations in the plant parts harvested (±SEM) and values of total N in grain and residue are shown on dry matter basis. Values represent means of three replicates and when followed by the same letter are not significantly different between treatments at $P < 0.05$.

	Yield kg ha^{-1}		N content %		Total N uptake kg ha^{-1}	
Treatment	grain	residue	grain	residue	grain	residue
1st year						
Wheat	2889 ± 21 a	5249 ± 21 a	2.23 ± 0.039 a	0.28 ± 0.002 a	57.0	13.7
Vetch	1917 ± 426 b	3981 ± 406 b	4.93 ± 0.014 b	1.69 ± 0.002 b	85.4	61.6
Chickpea	5144 ± 125 c	7711 ± 193 c	3.72 ± 0.017 c	0.49 ± 0.004 a	173.5	34.5
Broad bean	2049 ± 166 b	2818 ± 236 ac	3.96 ± 0.006 ac	0.50 ± 0.002 a	73.7	12.7
2nd year						
Wheat after						
Wheat	973 ± 64 a	1585 ± 117 a	1.56 ± 0.157 a	0.27 ± 0.002 a	15.2	4.3
Vetch	3981 ± 23 b	4197 ± 47 b	2.00 ± 0.046 b	0.36 ± 0.092 b	79.2	15.0
Chickpea	1261 ± 121 c	1873 ± 66 a	1.67 ± 0.029 d	0.29 ± 0.017 d	21.1	5.5
Broad bean	2089 ± 26 c	2432 ± 39 a	1.81 ± 0.038 c	0.32 ± 0.032 c	37.9	7.8

whereas wheat following wheat was ranked last at all variables. The same ranking between treatments was also shown by crop's harvest index (0.49, 0.46, 0.40 and 0.38 for vetch, faba bean, chickpea and wheat, respectively). Soil N at harvesting was always less than 5 mg kg^{-1} soil and statistically non-significant between treatments.

Laboratory incubations

Soil samples without plant residues exhibited similar patterns of N mineralization (Figure 1) with gradually increasing inorganic N contents. Mineral N concentration was almost equal to that of nitrates since ammonium was always very small. Nitrogen mineralization potential as it is given by the asymptote estimates of fitted curves are shown in Table 4. Figure 1 shows that N released from the soil cultivated with vetch produced the highest amount of mineral N, throughout the incubation period of 134 days. Inorganic N in this treatment overpassed 100 mg N kg^{-1} soil and was almost stable after 90 days. Soil cultivated with faba bean produced 67 mg N kg^{-1} at the end of the incubation, whereas chickpea and wheat soils showed the smallest mineralization potential (43 and 32 mg N kg^{-1} soil respectively, Table 4).

Significant amounts of residual N (values of mineral N at time 0 in Figure 1) were already present in soil during second season crop sowing at the vetch and faba bean plots (33 and 14 mg N kg^{-1} dry soil respectively), whereas only small concentrations, not significantly different between them, were measured at the wheat and chickpea soils. Based on the above results the amounts of mineral N accumulated in soil exclusively during the 134 day incubation were 84.3, 66.3, 39.5 and 27.3 mg N kg^{-1} soil for vetch, faba bean, chickpea and wheat, respectively. These values were obtained by subtracting residual N from mineral N measured at the end of the incubation.

The soil respiration rates peaked during the first days of incubation and then decreased to lower levels. Differences between treatments were kept, however, unchanged during the whole incubation period. Hence, cumulative CO_2–C release data indicated a clear difference in biological activity between samples coming from the wheat plots, which released significantly less CO_2 than samples from the legume

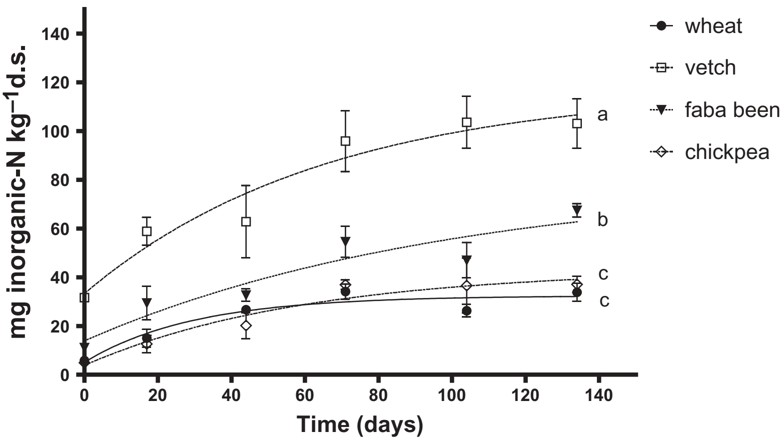

Figure 1. Inorganic N extracted from soil (mg kg dry soil^{-1}) in relation to time of laboratory incubation. Soils were sampled from plots which had been cultivated with vetch, faba bean, chickpea and wheat. Each point is the mean of three replicate plots, and bars associated with the points represent the standard error of the mean. Lines were obtained when data were fitted to the first-order exponential model $N_t = N_{max}(1 - e^{-kt})$. Values at the end of the incubation followed by the same letter are not significantly different between treatments at $P < 0.05$.

Table 4. Maximum mineralization potential (N_{max}) and initial mineral N values ($N_{t\,=\,0}$) obtained when data of Figure 1 were fitted to the first-order exponential model $N_t = N_{max}(1 - e^{-kt})$. Soil N concentration data (mg kg^{-1} of dry soil) were converted to N on an area basis (kg ha^{-1}) using 1 as the bulk density of soil and assuming a soil depth of 30 cm.

N parameter	Wheat	Vetch	Faba bean	Chickpea
		mg kg^{-1}		
N_{max}	32.4	117.5	80.0	43.3
N_t . t = 0	5.1	33.2	13.8	3.8
		kg ha^{-1}		
N_{max}	97.2	352.5	240.0	129.9
N_t . t = 0	15.3	99.6	41.4	11.4

plots (Figure 2). Among them, vetch showed significantly higher respiration rates than chickpea and faba bean, which did not differ statistically between them.

The decomposition of residues mixed with soil induced a very rapid N immobilization (Figure 3). The net reduction of soil mineral N by microorganisms and the period of immobilization were dependent on the type of plant residue. In relation to these variables the species were ranked in the order: vetch < faba beans < chickpeas = wheat. Vetch immobilized 11 mg N kg^{-1} soil and required 60 days to get out of the net immobilization phase while faba bean immobilized 9 mg N kg^{-1} reaching the initial level of mineral N after 75 days.

Discussion

Laboratory incubation experiments allow generalizations about N mineralization potential, which are more difficult to draw by field studies, because obtained results are not

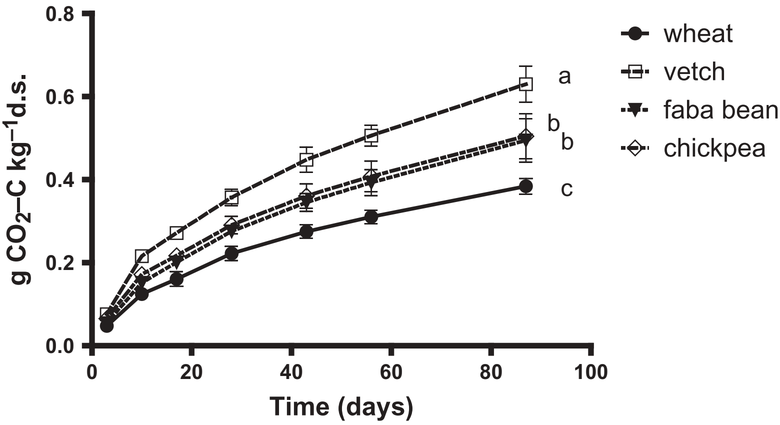

Figure 2. Cumulative CO_2–C (g kg dry soil^{-1}) release during laboratory incubation of soils coming from vetch, faba bean, chickpea and wheat plots. Each point is a mean of three replicate plots, and bars associated with the points represent the standard error of the mean. Values at the end of the incubation followed by the same letter are not significantly different between treatments at $P < 0.05$.

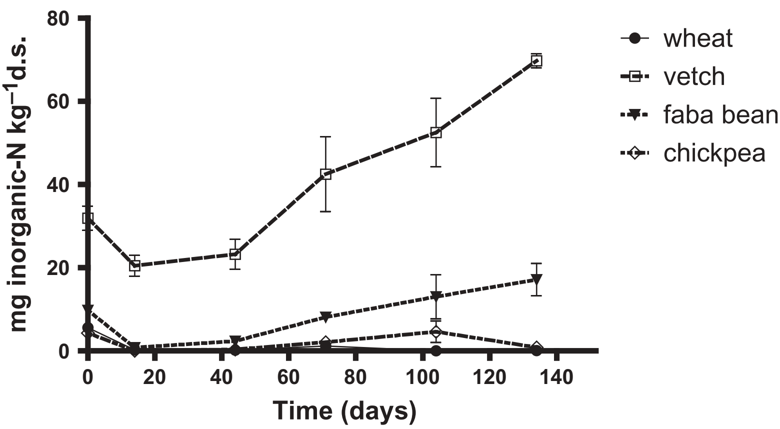

Figure 3. Inorganic N extracted from soil + residue mixtures (mg kg dry soil^{-1}) in relation to time of laboratory incubation. Soils and residues were sampled from vetch, faba bean, chickpea and wheat plots. Each point is the mean of three replicate plots, and bars associated with the points represent the standard error of the mean.

influenced by local or seasonal weather conditions, N losses and agricultural practices. As expected the optimum conditions of soil incubations in this study resulted in much greater mineral N than 'true' soil supply potential revealed by N uptake in plants grown in the field plots (Figure 1 and Table 3).

Nitrogen mineralization potential is an index of soil fertility (Thicke et al. 1993) which varies widely with regards to cropping history, agricultural practices such as tillage and incorporation or not of residues but also to the time of season (Stanford et al. 1973). In the field, fresh litter input is not continuous and regular throughout the season as well as temperature and moisture conditions causing significant difference of this index when it is carried out on soil samples during, before or after the growing season of a crop. It is claimed that estimates of nitrogen mineralization in this study, which refer to the potential at the time of sowing, are more useful from the agronomic point of view and more closely related to the production realized by a crop.

Mineralization of nitrogen for the vetch soil was shown to reach 350 kg N ha^{-1}, assuming an even potential down to 30 cm from the soil surface (Table 4). This amount would be sufficient to support wheat biomass production three times greater than the one found during the second season of the rotation (Table 2). Although full mineralization potential cannot be realized in the field due to non-optimum temperature and moisture conditions for microbial activity and eventual leaching and runoff of nitrate-N, results provide clear evidence why vetch may satisfy the entire N needs of a subsequent crop without inorganic N fertilizer even taking into account that part of the available N will be used for root production, which has not been measured. It is anticipated that N mineralization potential would be even greater if vetch was incorporated in soil during flowering; an agricultural practice that has already been found to increase yields of the following wheat to a greater degree than vetch which has been left to fill grain (Dalias 2012). An actual N mineralization as low as 50% of the maximum potential (Table 4) would also be sufficient to sustain a 3 t ha^{-1} production of wheat following faba bean even without inorganic fertilizer application.

Evidence of nitrogenous benefits of wheat coming from the preceding vetch and faba bean crops came in the present experiment from both the amount of residual inorganic N at germination and the amount of N released during its vegetative period. However, although wheat received a nitrogenous benefit from chickpea (Table 3), this was verified neither from residual N results nor from soil incubation results. López-Bellido et al. (2004) reported also very small contribution of chickpea N (50 kg ha^{-1}) to subsequent wheat. Nevertheless, soil respiration of the chickpea was greater than the control soil of the wheat plots indicating an increased microbial activity after this legume cultivation. Unfortunately, due to the exhaustion of available mineral N in the soil-residue mixtures, results could not reveal eventual differences between chickpea's and wheat's immobilization potential (Figure 3), which could ultimately account for the realized N yield surplus of wheat during the second season of the rotation in chickpea plots.

The benefit of legumes on subsequent crops is commonly attributed to the total quantity of litter added to the soil and their chemical quality (Odhiambo 2010). Hence, it was hypothesized that N mineralization in this study would simply reflect the quantity of N input (Frankenberger & Abdelmagid 1985) or the C/N ratio of litter (Vanlauwe et al. 1997). Vetch soil that received the greatest total N input with the lowest C/N ratio actually exhibited the highest mineralization rate, but the other three soils were not ranked at the same order as their C/N ratios or total residue N would indicate. However, in rotation systems such as these investigated in the present experiment, where harvesting of the first season crop occurs almost six months before second season crop sowing, most litter material would have already been processed by microbial biomass so its dynamics might be less affected by initial residue properties. It is generally recognized that the factors which control decomposition change with time and that initial properties of litter are less important at later stages of decomposition (Heal et al. 1997).

Nitrogen benefits in legume–cereal rotations are frequently explained by smaller immobilization of N during the decomposition of legume compared with cereal residues (Green & Blackmer 1995). Although immobilization cannot be considered as a loss but rather as a temporary storage of N, which will be re-mineralized under the appropriate conditions (Jansson & Persson 1982; McSwiney et al. 2010), it may affect the dynamics of mineral N during the growing phase of a crop. Fosu et al. (2007) showed that the same mechanism can also be used to explain differences of N benefits among legume species.

In the present study incubations showed also significant net immobilization of N when plant residues were incorporated in soil. For the same amount of residue incorporation and the same moisture and temperature conditions, soil receiving vetch residues will more rapidly get out of the net immobilization phase. This is probably one of the reasons of the greater residual N of vetch plots found in late autumn and one of the reasons why vetch is generally considered to have a greater N carry over effect to subsequent crops. However, soil samples without addition of residues taken 2 cm below soil surface did not show any net immobilization phase. Based on current results, therefore, it is difficult to account on the importance of N immobilization in the field. At sowing, the eventual net immobilization phase seems to have already been completed or never affected soil that was not in direct contact with crop residues left on soil surface. After tillage, which was carried out just before sowing, laboratory results cannot provide adequate information on the contribution of immobilization to soil N availability as this is controlled by total residue quantity, sizes of fragmented stems and leaves and their distribution in the soil profile.

Conclusions

Results of the present study validated once more the assumption that growing cereals after grain or forage legumes reduced the need of N fertilizer and enhance soil productivity compared with continuous cereal production. Vetch was shown to be superior in providing available N to the following wheat, but faba bean also was proved to affect significantly wheat's N nutrition showing greater residual N than the control and higher rates of soil N mineralization. It is underlined, however, that the present work refers only to immediate effects of legume on N dynamics. Long-term effects on organic matter or organic N pool would demand data of complete N balance analysis or many rotation cycles.

It is concluded that the introduction of these grain legumes in wheat–legume rotations is a valuable choice of farmers and that nitrogenous benefits can reasonably be considered as a surplus to the widely recognizable paybacks coming from soil quality improvement, reduced incidence of pests and optimized water use (Kirkegaard et al. 2008).

Acknowledgements

The author wishes to thank T. Louca and M. Elia for technical assistance and A. Pallides for linguistic improvement of the text.

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