SOIL ORGANIC CARBON AND NITROGEN STATUS UNDER FALLOW AND CEREAL-LEGUME SPECIES IN A TUNISIAN SEMI-ARID CONDITIONS

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ABSTRACT

Proper crop rotation might help to conserve soil fertility among small scale farmers in dry areas. A study was carried out at Tunisia station to evaluate the effect of crops in the rotation on evaluation and some nutrient status. Crops involved wheat, barley, oat, and faba bean. Results showed that fallow maintained the original SOC content during all the cropping season followed by faba bean species. Significant difference was observed in residual SOC content left under fallow and various plant at harvest (P=0.0367) we observed that only fallow maintained the original SOC content at the end of the cropping season. All used crops have decreased the level of the original SOC. fallow maintained the higher total soil nitrogen level than various plant species (P=0.0018) during all cropping system. For the mean of all plant species, the total nitrogen was greater during March 22 followed by in the order of February 7 and March 7. At harvest, total nitrogen was influenced by plant species (P=0.0356), it reduced to 16% in fallow treatment and was 7.2% higher total nitrogen concentration than barley pots 20.7% than oat, 23.4% than wheat and 28.2% than faba bean treatment. The mineralized organic matter was more during the first period from February 7 to April 22.

Keywords: Soil organic carbon, Growth stages, Cereal species, Faba bean, Fallow.

INTRODUCTION

Sustainability of crop production systems depend on selected farming practices that allow the balancing of nutrient output and the preservation of soil organic matter (Zotarelli 2012). Soil organic matter (SOM) is essential to all soil processes that have an impact on crop production and the environment. Soils of the semi-arid Mediterranean region are low in SOM due to environmental conditions (temperature, moisture) and centuries of cultivation. Hence, as SOM has a major influence on soil aggregation, nutrient supply, and soil moisture, as well as the relationships between them, there is a need to assess the impact of crops and cropping.

Crop rotations are effective in improving soil physical, chemical and biological characteristics (Verma and Shekhawat, 1991). The physical characteristics include increased soil aggregate stability, decreased crusting of soil surfaces, increased granular structure and friable consistence (Bullock, 1992). The effect of crop rotations on soil nitrogen (N), phosphorous (P), potassium (K) and carbon (C) is very complex (Bullock, 1992). It has been reported that including deep-rooted cover crops in rotations helps to distribute phosphorous and potassium from deep within the soil profile to the soil surface, where plant roots have better access to them (Marschner, 1990; Clark et al., 1998). A shallow-rooted crop may be followed by a deeper-rooted crop to recover nutrients that were unused by the shallow feeders and may have leached by irrigation or rainfall to lower depths in the soil profile. Conversely, a deep-rooted heavy feeder may be followed by a shallow-rooted light feeder to scavenge nutrients that may remain after heavy applications of nutrients (Clark et al., 1998; Bullock, 1992). Examples of heavy feeders are maize, potatoes, vegetables and soybeans while light feeders include grass sods, legume sods, wheat, barley and oats (Clark et al. 1998).

In addition, legumes in crop rotations supply biologically fixed atmospheric nitrogen to the soil thus as a replacing or supplementing inorganic nitrogen fertilizer. The amount of nitrogen in legume crops varies among species, but legumes generally contribute 50 to 200 pounds of nitrogen per acre (Flint and Roberts, 1988; Clark et al., 1998). This nitrogen is mineralized over an extended period of time, so that any surplus of it does not readily run off into streams and underground water supplies. Researchers estimate that from 40 to 75 percent of the total nitrogen contained in a legume cover crop is available in the soil for subsequent crops, depending on environmental conditions (Clark et al., 1998; Utomo et al., 1992). Low soil fertility among small scale farmers in Tunisia is mainly caused by continuous cultivation without a fallow period and inclusion of legumes in rotation. This is worsened by inadequate crop rotation due to small farm sizes (Kaguongo et al., 2008). The crop under rotations practiced in Tunisia mainly involve wheat, barley, oat, faba bean, chickpea, lentil, vetch and other forage legumes.

Fallow was a traditional practice to conserve soil moisture, but because of land-use pressure it is giving way to cereal monoculture, which is unsustainable (Ryan, 2009). As continuous cropping is unsustainable, mainly because of disease buildup, the introduction of crop rotations is a logical replacement for fallow (Harris 1995). Crop management practices have a tremendous impact on both soil fertility and soil organic carbon (SOC) (Campbell, 2000). Continuous cropping or decreasing the frequency of summer fallow in cereal-based dryland rotations may have benefits other than greater water utilization and erosion control.

Soil organic matter under wheat rotations, compared to those of continuous wheat under rainfed and irrigated was increase in term of point percent- age by 5.1 and 4.4, respectively. The rotations of mixture and meadow under both irrigated treatments increased the point of percentage of organic matter over continuous wheat (Martiniello2012). Keeping these points in view, the present investigation was carried out with aims to study the changes in soil organic matter and some nutrients status all over the growing season under fallow and various plant species in order to select crops in the rotations which maintain higher soil organic matter and fertility levels at harvest.

METHODOLOGY

Experimental details

A pot experiment was carried out in the semi-arid region of Le Kef, Tunisia during 2011-12. The experiment was laid out in completely randomized design with three replications. The treatments consist of durum wheat (*Triticum durum* cv Karim), barley (*Hordeum vulgare* cv Manel), oat (*Avena sativa* cv Creme), faba beans (*Vicia faba* cv Super Aguadulce) and a fallow (control treatment) and nine sampling dates during crop growth stages. The four crop species treatments *viz.*,(wheat, faba bean, barley, oat, and control(fallow) replicated thrice the whole. These 15 pots were replicated in 9 times for sampling date to allow destructive sampling. We the pots were 135 and harvested 15 pots in each sampling dates for analysis. The parameters like organic carbon, total nitrogen, NO_3- Nitrogen, NH_4-Nitrogen, were recorded in each sampling date. The prevailing meteorological data during 2011-12 in the experimental site where soil sample were collected for present study is presented in Table 1.

Table 1: Monthly rainfall and temperature recorded at the experiment site of Boulifa during the cropping season of 2011-2012

Months	**December**	**January**	**February**	**March**	**April**	**May**	**June**
Average of minimum temperature (^{0}C)	7.29	6.58	4.26	7.54	10.20	11.70	18.90
Average of maximum temperature (^{0}C)	16.54	14.90	13.21	19.32	22.46	27.93	36.53
Rainfall (mm)	57.00	88.40	132.20	74.40	44.60	23.00	00

Source: Meteorological office of Boulifa, Kef

The soil samples from site of Higher School of Agriculture rotation trial including fallow (cereal/ fallow) were collected from 0-20 cm depth alluvial/colluvial material of Le Kef plain (Inceptisol) and the soil was collected from wheat phase. In the rotations, the field was left wheat during previous cropping season (2010-11). Collected soil samples were mixed with sand in proportions (3:1) and filled in 5 kg pots for pot culture experiment. A composite soil sample was analyzed for particle size distribution, pH, organic matter content, total N, available P and exchangeable K before initiating the experiment. Some physico-chemical properties of the experimental soil are shown in Table 2.

Table 2: Physico-chemical properties of the experimental soil

Characteristics	**Value**
Sand (%)	33.1
Silt (%)	30.6
Clay (%)	33.30
Texture class	Clay loam
Soil pH	8.0
Organic matter (%)	1.37
C/N ratio	8.87
Total N (%)	0.089
Available P (mg kg^{-1})	75.70
Exchangeable K	477.20

Low dose of N, P, and K concentrations was given to all the treatments except the fallow treatment. The treatments (except fallow pots) received flat rates of ammonium nitrate (cereals crops 0.2 g pot $^{-1}$ and faba bean 0.12g ammonium nitrate pot^{-1} = 20kg N ha^{-1}), triple superphosphate (0.4 g pot $^{-1}$ = 200 kg ha $^{-1}$ of triple superposphate) and potassium sulfate (0.3 g pot $^{-1}$ = 150 kg ha $^{-1}$ potassium sulfate) before sowing the seed. In cereal crops, ammonium nitrate (0.2 g pot $^{-1}$ = 100 kg of ammonium nitrate ha^{-1}) was top dressed at tillering stage. Sowing rate was 3 seeds pot^{-1} for faba beans and 15 seeds pot^{-1} for the cereal species in January 7. Seeds were placed manually in the center of each pot. At emergence, the plants were thinned and maintained one plant per pot. Throughout the growing season, the plants were watered uniformly to maintain soil moisture at field capacity. Weeds were removed manually.

Soil sample was collected at 31, 59, 74, 90,105,120,135,151 and 173 days after sowing for various analysis.

Soil analysis producer

Particle size analysis was completed on 50 grams of the air-dried, ground (2mm), composited soil samples using the hydrometer method Bouyoucos (1962). Soil pH was measured in distilled water on a 1:2 ratio of soil:solution (Hendershot et al., 1993) using pH meter. Soil inorganic N (NH_4-N and NO_3-N) content wasquantified by first extracting the inorganic Nusinga 2M KCl solution (Maynard et al., 2007). Both NO_3^- and NH_4^+ contents in the soil extracts were quantified by continuous-flow injection analysis on a Lachat instrument (Lachat Instruments, 2005). Ammonium concentration was determined by the salicylate-nitroprusside method (method 12-107-06-2-A), whereas nitrate was measured using the cadmium-copper reduction procedure (method 12-107-04-1-B).

The air-dried subsamples were groundedat 100 mesh, and total N concentrations were determined by dry ashing with a LECO CNS-1000 (LECO Corp., St. Joseph, MI). Available soil P was determined using Mehlich-3 extraction method(Mehlich, 1984). Mehlich-3 extractable cations (K) were determined by inductively-coupled plasma optical emission spectroscopy (ICP-OES; Model 4300DV, Perkin Elmer, Shelton, CT).

Statistical analysis

For every compound in the results there is at first a global test to know which effects are significant among species and sampling date and interaction of species * sampling date. The multiple comparisons are then presented for the effects which are significant. When the interaction is significant, the multiple comparisons are made by fixing the sampling date and the species. Then "sliced effects" are made in the case of significant interaction, to know for which species and for which sampling date there are differences. The probability of 0.05 was used for the multiple comparisons with a correction StepDown Bonferroni. All the analyses with the factor species only, are made for the harvesting sampling date(SAS Institute, 2001)

RESULTS AND DISCUSSION

The ANOVA revealed that the effect of plant species and stage of growth were influenced significantly on N-NO_3 (Table 3). However, total nitrogen, organic carbon, C :N ratio, and N-NH_4 were found non significant. The results of each parameters are discussed in details under various headings.

Table 3: Significance of main effects of plant species and stage of growth, and their interactions on several chemical parameters

Effects and interaction	Total nitrogen	N-NH_4	N-NO_3	C:N ratio	Organic Carbon
Plant species(Sp)	0.0018	0.0461	0.0003	ns	<0.0001
Stage of growth (D)	<0.0001	<0.0001	<0.0001	0.0309	0.0347
Sp*D	ns	ns	<0.0001	ns	ns

ns: no significant difference at level of 5%

Soil organic carbon

Soil organic matter is a primary indicator of soil quality, and increases in SOM can enhance soil fertility and increase plant growth (Rice, 2005). Chemically, SOM increases the cation exchange capacity of the soil. Twenty to 80% of the cation exchange capacity of the soil is due to soil organic matter content. These cation exchange sites are important for retention of nutrients in the soil. Associated with the organic carbon are organic –bound nitrogen, phosphorus, and sulfur, which upon decomposition provide slow release of nutrients for plant production (Rice, 2005).Analysis of variance has shown a significant difference among species (P<0.0001) and growth stages. However, no significant interaction between species and stages of growth was found (P=0.1321) (Table 3). The SOC was greater during third sampling date (March22) and less during May 07 (Fig. 1).

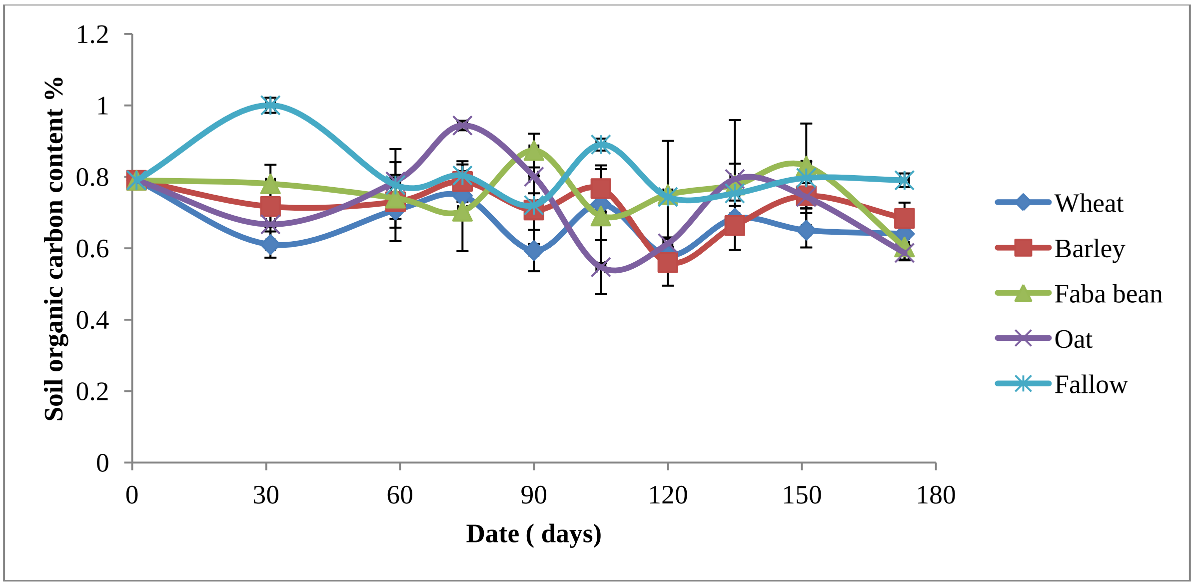

Figure 1. Changes in soil organic carbon levels with growth stages under fallow and various plant species.

Fallow maintained the original SOC content (0.79%) during all the cropping season followed by faba bean species. The lower SOC was found in wheat as compare to fallow and was probably due to the higher rate of mineralization of organic compounds. Among plant species, faba bean was shown to leave a higher amount of organic matter in the soil than the cereal species (Fig. 2).

The lower SOC in the cereals might be due to continuous growing of cereals after cereals as monoculture. The negative prominent impacts of monoculture are fauna impoverishment, increased number of crop pests, declined activities of dehydrogenase and phosphatase, and higher phenolic acids in the soil. Although continuous wheat increased microbial biomass and alfalfa haycrop increased inorganic N significantly, continuous monoculture is not sustainable for many crops unless counter measures are taken to deal with.The inclusion of legume crops in the rotation increase the liable carbon concentrations compared with continuous wheat or a long fallow period (Blair and Crocker, 2000). Similarly, Acosta-Martinez et al. (2004) concluded that continuous monoculture systems had a negative impact on soil function and sustainability.

The impacts of continuous monoculture systems on SOC, soil function and sustainability differed among crops (Russell and Jones 1996, Ryszkowski et al. 1998). Organic acid secretion has been extensively studied in white lupin for its role in cluster root metabolism and P solubilization. wheat is generally recognized as a species with a low carboxylate release (Nuruzzaman et al., 2006; Pearse et al., 2006,) lupin and wheat grown in same soil conditions, they observed that differed greatly in amounts of organic acids, with an 80-fold difference in amounts of organic acids in the rhizosphere of the two species. Similarly, Weisskopf (2008) measured greater organic acid concentrations under lupin than wheat over a 12-month period. In the rhizosphere soil samples, organic acids were present in very low amounts, compared to the root samples, malate was present in roots of lupin, but barely detectable in wheat.

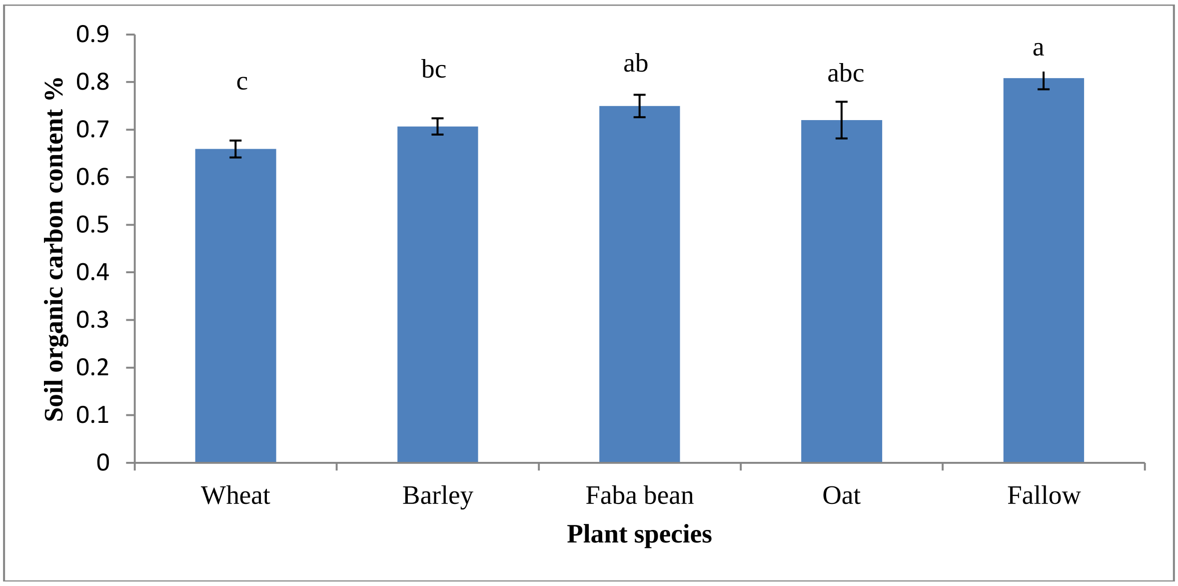

Figure 2.Annual mean soil organic carbon content at various growth stages under fallow and various plant

Significant difference was noticed in residual SOC content left under fallow and various plant at harvest (P=0.0367) (Fig. 3).Only fallow maintained the original SOC content (0.79%) at the end of the cropping season. All used crops have decreased the level of the original SOC. Barley lost around 13.7% of original concentration of SOC followed by wheat (19.2%), faba bean (23.6%) and oat (26.5%).The low storage of carbon was probably attributable to rapid mineralization due to high oxidation rates and to greater microbial activity because of changes in soil moisture and aeration (Doran and Smith, 1987). In several studies there are an increase in stored (SOC) with depth observed under conventional tillage, (Jemai, 2012, 2013 Deen and Kataki, 2003; Hernanz et al., 2002, 2009), may result from the shifting of crop residues into the subsoil and their consequent protection from erosion and microbial decomposition (Lal, 1982; Yang and Wander, 1999).

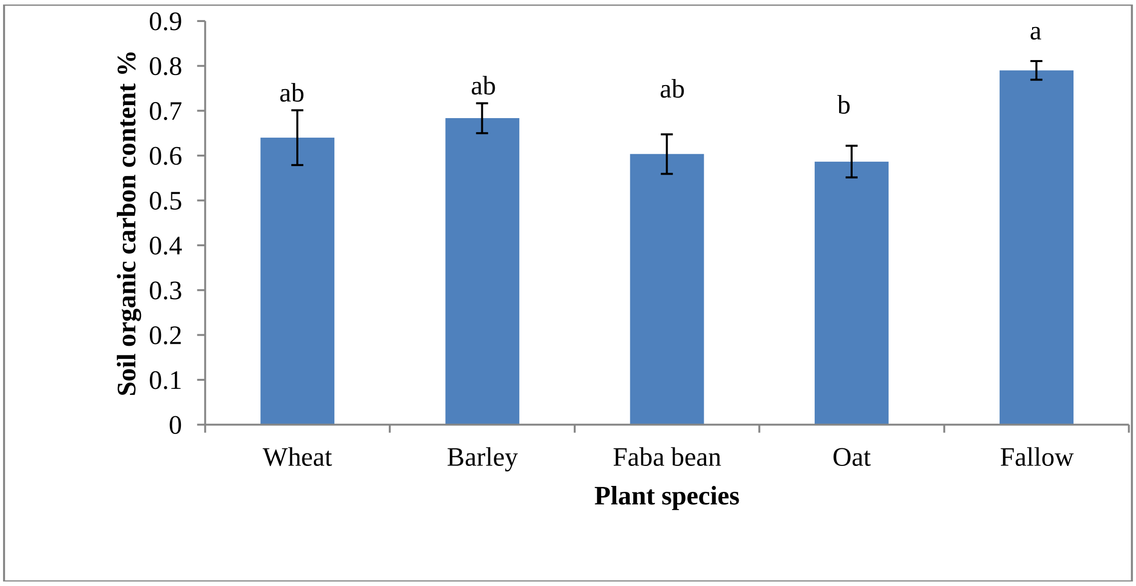

Figure 3. Residual soil organic carbon content left under fallow and various crops at harvest

Total soil nitrogen

Total nitrogen concentrations were significantly influenced by plant species and growth stages. However their interaction was not significant (Table 3, Figure 4).

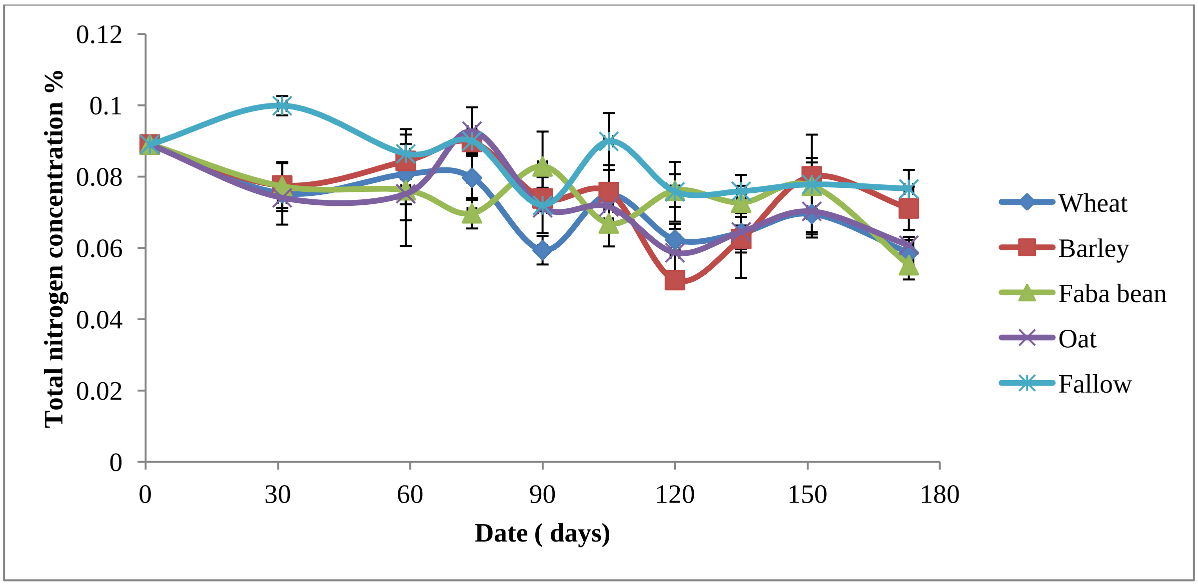

Figure 4. Changes in total soil nitrogen concentrations with growth stages under fallow and various plant species.

Data showed that the fallow maintained the higher total soil nitrogen level than various plant species (P=0.0018) during all cropping system (Fig. 5). For the mean of all plant species, the total nitrogen was greater during March 22 followed by in the order of February 7 and March 7. The less concentration of total nitrogen was recorded during the harvest date (June 29).

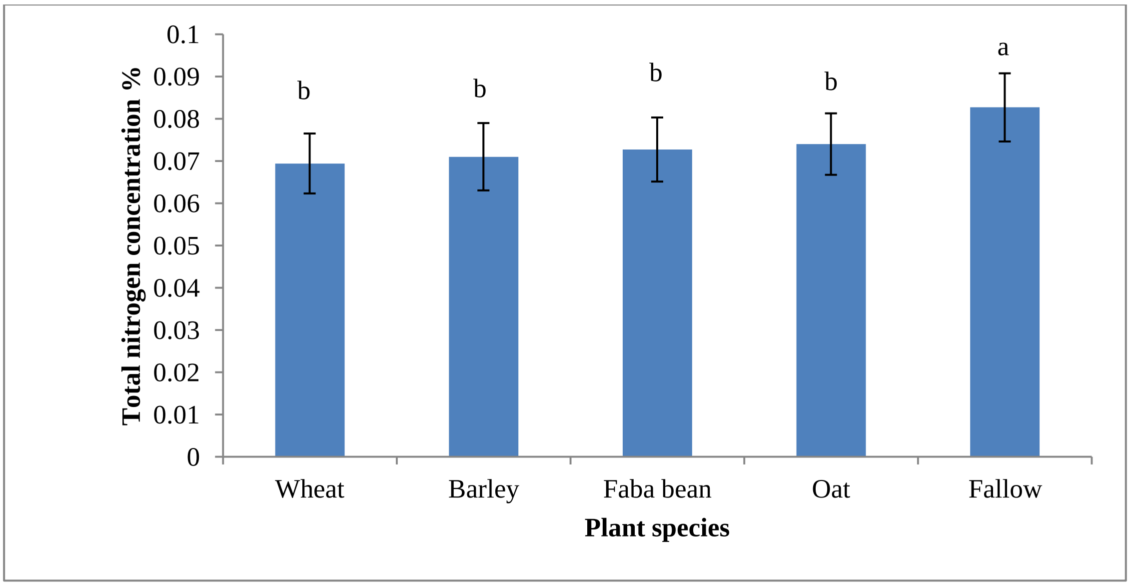

Figure 5.Annual mean total soil nitrogen concentration at various growth stages under fallow and various plant

At harvest, total nitrogen was influenced by plant species(P=0.0356). Total nitogen concentration was 0.089% in the begining of the experiment. However, it reduced to 16% in fallow treatment at harvest and recorded a value of 0.076%. The fallow pots were 7.2% higher toal nitrogen concentration than barley pots 20.7% than oat, 23.4% than wheat and 28.2% than faba bean treatment (Fig. 6). According to Bermer (2000) the soil total N decline under the fallow-wheat rotation, but increase under the 6 year fallow-cereal-hay (grass-legume)

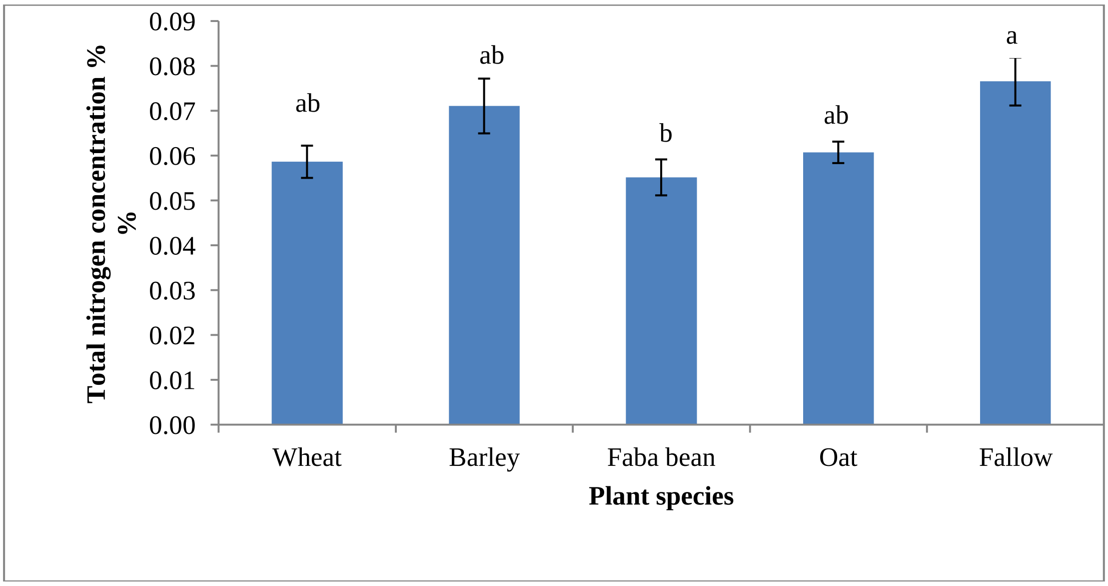

Figure 6. Residual total soil nitrogen concentration left under fallow and various crops at the end of the growing season

Carbon-Nitrogen ratio

Table 4: C:N ratio for the residual soil organic matter under fallow and various plant species.

Plant Species	Wheat	Barley	Oat	Faba bean	Fallow
Organic carbon (%)	0.64^{a} (0.06)	0.68^{ab} (0.03)	0.58^{b} (0.04)	0.60^{ab} (0.04)	0.79^{a} (0.02)
Total soil nitrogen (%)	0.058^{ab} (0.004)	0.071^{ab} (0.006)	0.060^{ab} (0.002)	0.055^{b} (0.004)	0.076^{a} (0.005)
C:N Ratio	10.89^{a} (0.59)	9.73^{a} (0.79)	9.65^{a} (0.31)	10.95^{a} (0.40)	10.39^{a} (0.49)

Value in the paranthesis are indicates Standard Error

The carbon-nitrogen (C: N) ratio was significantly influenced by stage of growth but plant species interaction effect was non-significant. The mineralized organic matter was more during the first period from February 7 to April 22 in all the plant species and the value was around 9 (Table 3).

At harvest, ANOVA revealed no significant difference among plant species with regard to the organic matter mineralization process (P= 0.357). However, oat and barley released into the soil a slightly more mineralized organic matter compared to other species and fallow (Table 4). The C: N ratio of the residue, an important key in soil management, also varies, crop biomass is generally 40 – 50% but the nitrogen content considerably within and among species, Thus, an adequate supply of nitrogen may be required to build SOM for crops with a high C: N ration since C and N and their proportionality is relatively constant across a range of agricultural soils at about 10:1(Reicosky and Wilts, 2005)

Ammonium-nitrogen (NH_4^+)

The concentration of $NH4^+$ nitrogen was significantly influenced by plant species (P=0.0461) and growth stages (P<0.0001) but not by their interaction (Table 2). The greater value was recorded during the period of June 7, followed by May 7 and June 29. However, the lower value was recorded in February 7 sampling date (Fig. 7).

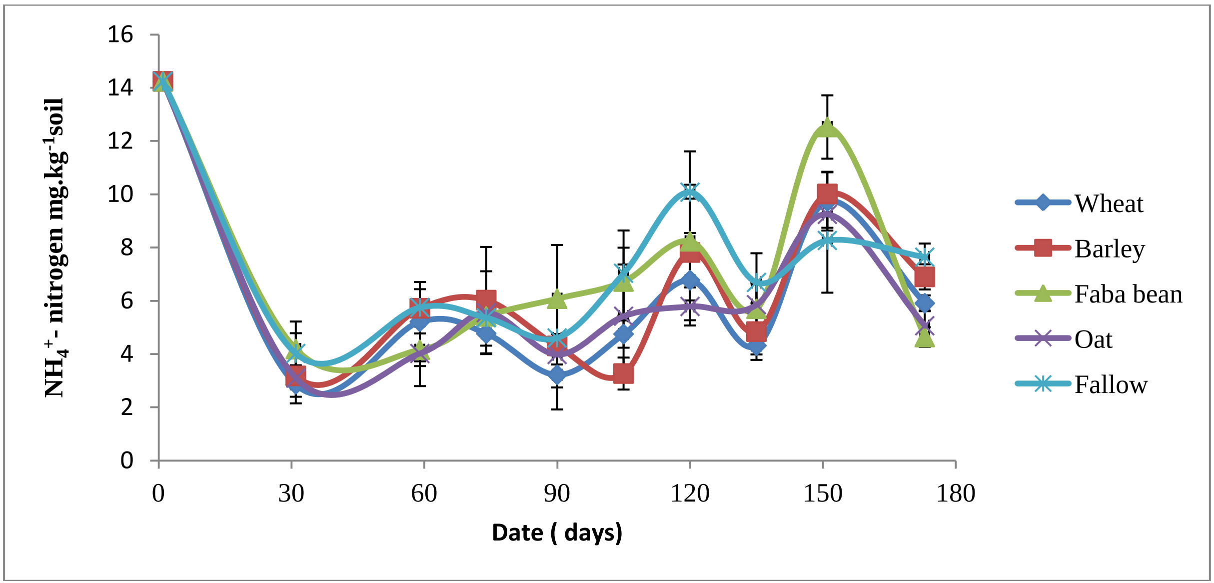

Figure 7. NH_4^+ - nitrogen left into the soil at the end of the growing season under fallow and various plant species.

At harvest the concentrations of NH4$^+$- nitrogen was significantly influenced by plant species (P= 0.0045). Higher NH4$^+$- nitrogen concentration was recorded in fallow pots (7.63 mg/kg) and it was 9.7 % higher than barley, 22.7 % than wheat, 33.8 % than oat and 39.4 % than faba bean pots (Fig. 8). This was in agreement with Corbeels (1999). However, Ryan (2009) recommended the use of forage legumes rather than fallow and continuous cropping in cereal crop rotations.

We can explain this result by the strategy adopted for fertilisation in semi-arid climate and not by the residual nitrogen by cereal crop, in fact for cereal crop we put topdress nitrogen two time in the begining with sowing and during the tillering. However for faba bean we applied nitrogen fertilisation only with the instalation of the experiment like starter fertiliser, for this we find more residual ammonium with cereal species than faba bean, fallow left the high ammount of nitrogen at the harvest. Angus (2001) reported that in a dryland cereal there was a problem of matching soil N supply with an unpredictable N demand.

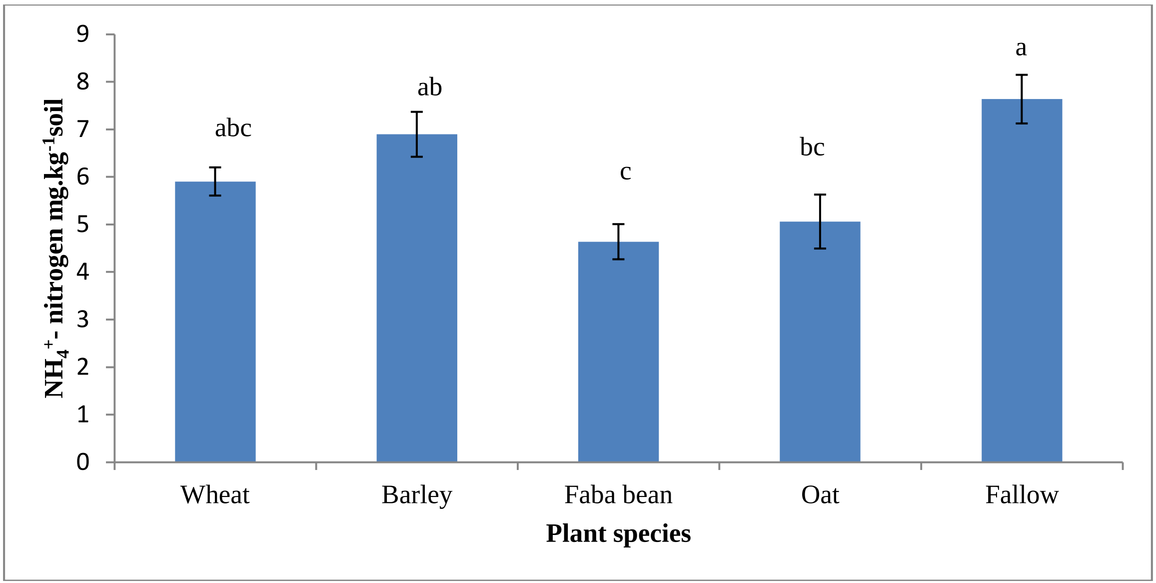

Figure 8. NH$_4^+$ - nitrogen left into the soil at the end of the growing season under fallow and various plant species.

Nitrate-nitrogen (NO$_3^-$)

As it is well known nitrate ions are very mobile in soils and their concentration is usually related to water dynamics. Hence, leaching losses of nitrates are very common and were perfectly shown in figure 9 where a high variation in nitrate concentration all over the growing season, regardless of the tested plant species, was observed.

NO$_3^-$- nitrogen concentration in the soil was significantly influenced by plant species (P= 0.0003), growth stages, and their interaction (Table 3). The greater value was recorded during last sampling in faba bean pots(13.07 mg kg^{-1}), At harvest, the concentration was influenced by plant species.

Rayn et al(2009) found that rotation and sampling date had significant effect on soil mineral nitrogen and also the interaction between them was significant and in most case values from the medic legume rotation were highest.

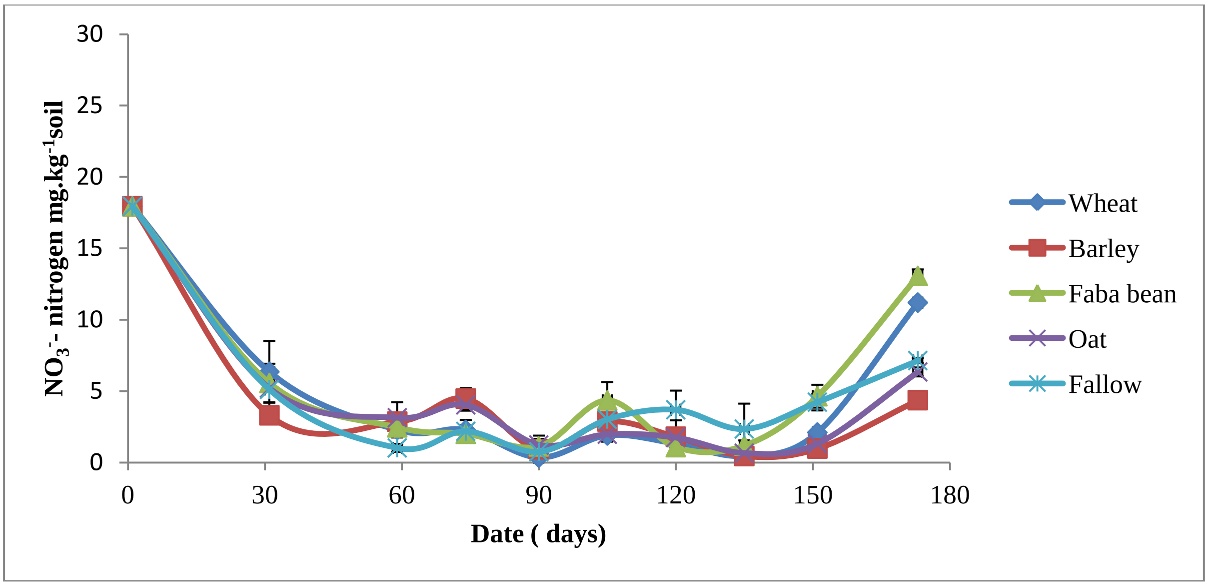

Figure 9. Changes in NO_3^-- nitrogen concentration in soil over the growing season under fallow and various plant species.

CONCLUSIONS

The dynamic processes that influence soil quality are complex, and they operate through time at different locations and situations. Soil organic matter is both a source of carbon release and a sink for carbon sequestration. Cultivation and tillage can reduce and change the distribution of SOC while an appropriate crop rotation can increase or maintain the quantity and quality of soil organic matter, and improve soil chemical and physical properties. The return of crop residues and the application of manure and fertilizers can all contribute to an increase in soil nutrients and SOC content, but would need to be combined into a management system for more improvement. The negative prominent impacts of monoculture are influenced by crop type with fauna impoverishment, an increased number of crop pests, a decline in activities of dehydrogenase and phosphatase, and increased levels of phenolic acids in the soil. SOC can only be preserved by using crop rotations with reduced tillage frequency and additions of chemical fertilizers, crop residues and/or manure. Continuous monitoring of long-term changes in the SOC and soil quality under conservation tillage in different agro-ecological zones is essential. There is also a need to obtain more data on longterm effects of different tillage systems on carbon and nitrogen mineralization and immobilization in various field situations. The issue involved in understanding soil quality and the design of crop and soil systems for agricultural sustainability should be more holistic, and it needs further investigation.

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