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Effect of mixed cropping rotations of vetch barley and fodder pea-barley with corn on the chemical, physical and biological soil caracterestics in the Southwest of Morocco

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Abstract*:* The aim of this work was to study the inclusion of vetch and fodder pea mixed with barley in the cropping systems and evaluates the effects of crop rotations on the chemical, physical and biological soil characteristics in the Southwest of Morocco. The experiment was conducted at two Experimental Stations during 2009-2010, 2010-2011 and 2011-2012 growing seasons. The experimental design was a complete block design and 4 replicates were adopted with unique factor and 4 treatments Vetch/barley, Fodder pea/barley, Barley and Corn. Main plots were different preceding crops maize. Results showed that soil pH was alkalinized for barley-corn rotation and corn monoculture and acidified for vetch/barley-corn and fodder pea/barley-Corn rotations. Vetch/barley-corn and fodder pea/barley-Corn rotations improve significantly organic matter and total nitrogen while barley-corn and corn monoculture make less. Soil physical and biological characteristics had affected positively by vetch/barley-corn and fodder pea/barley-Corn rotations and negatively by barley-corn and corn monoculture.

Keywords: Rotation, Barley, Corn, Vetch and fodder pea mixed with barley, Chemical, physical and biological soil characteristics.

Introduction

The arid climate in the Southwest of Morocco characterized by repeated drought affects the yield of forage especially corn. Additionally, the poor quality of livestock feed was accentuated because of the degradation of soil fertility due to monoculture of corn [1]. The water scarcity forces the farmers to reduce crop area and shift to drip irrigation instead of surface irrigation. Then, the use of fallow area and rotations were mainly affected especially, in the south of Mediterranean area [2][3]. The intensive use of mineral fertilizers without recycling crops residues decrease the amount of total nitrogen and organic matter [4][5][6][7][8].

Frequent rotations practiced in the region are barley-corn, continuous corn in the majority of livestock farmers. [1][9]have reported that crop rotation systems adopted in the Southwest of Morocco was barley-corn-barley, barley-corn-corn, barley-vegetables-corn, saffron-barley-corn and field bean- vegetables-corn. Many studies [10][11][12] showed that these rotations leads to negative balance of fertilizers elements and decrease the soil fertility. In an attempt to increase yields and competitiveness, conservation management practices are being disregarded, the predominant practices being crop monoculture, intensive tillage, and excessive use of pesticides [13]. Indeed, continuous corn without additions of inorganic fertilizers or manures resulted in an average of 52% decrease in organic matter compared to the 'original' condition [14][15]. Moreover, it has been frequently reported that soil under monoculture is prone to nutrient deficiencies and part of the instability of monoculture agro ecosystems can be also associated with a soil structure weakened by increased susceptibility to compaction, reduced water infiltration, and increased erosion [16]. These characteristics make monoculture systems less resilient to stress [17]. The inclusion of legumes in cereal-based rotations together with the appropriate use of nutrient inputs are considered to be the key to the rehabilitation and maintenance of soil fertility and productivity in intensifying cereal-based systems [18][19]. Vetch and pea are well adapted to the soil and climate in the Mediterranean and North African regions, including Morocco [20][21]. The aim of this work was to study the inclusion of vetch and fodder pea mixed with barley in the cropping systems and evaluates the effects of crop rotations on the chemical, physical and biological soil characteristics in the Southwest of Morocco.

Materials and methods

Field experiments were carried out at two locations in the Souss-Massa region for three successive growing seasons 2009-2010, 2010-2011 and 2011-2012. The first trial was done at the experimental farm of the INRA, Belfaa, Massa (11º

111 N, 07º 381E, and 686 m of altitude). Mediterranean climate is dominant in this location (The mean annual temperature was 19°C and the mean rainfall was 150 mm). Soil in this area is sandy- loam with pH (8.5), organic matter (0.98%) and total nitrogen (0.058%).

The second trial was carried out in the Rural County of Tizi N'Test, Province of Taroudant (55 ° 24N ', 23 ° 50 N). The climate in this area is Mediterranean semi-arid with cold winters (Mean annual temperature was ranged between 13.7 ° C in January and 26.2 ° C in July-August and the mean rainfall was 300 mm). The soil is heterocalcarous, xeric, brown-to black, clayey-sand with pH (8.1), organic matter (2.89%) and total nitrogen (0.14%).

Experimental Design

A complete block design and 4 replicates were adopted with unique factor and 4 treatments (Vetch/barley, Fodder pea/barley, Barley and Corn). Each plot (experimental unit) was 6 m long and 3m wide with a border between plots of 25 cm. Before sowing, seeds of barley and legumes (vetch or fodder pea) were mixed at 1:2 (v/v). Varieties used were Yamama for vetch, Forrimax for fodder pea, Amira for barley and local variety for corn. The sowing was carried out the first week of November and harvested during the first week of April. The Corn was the second cropping cycle in all 4 treatments and it was sowed during the 3rd week of May and harvested during the end of August. This sequence of cropping continued for three seasons from November 2009 to August 2012. The seeds were sown by hand drill at 5 cm depth. Table 1 showed the fertilizers used during two cropping cycle.

Table 1: Fertilizers used during 3 seasons of trial

Fertilizers	Composition	Dose (Kg/Ha)	Cropping cycle	Stage
Super-mono-phosphate	P_2O_5 (18%)	30	1	
Urea	N (46%)	15	2	6 leaves
Muriate of potash	K_2O (60%)	15	2	6 leaves
Urea	N (46%)	15	2	8 leaves
Muriate of potash	K_2O (60%)	15	2	8 leaves

The amount of water consumed was 350 mm/cycle including rainfall and irrigation supplements that have been made during dry periods. During the trials, no pesticides were sprayed.
Soil sampling: The samples were taken at 30 cm depth at the beginning and at the end of each crop cycle. The samples were composited, shade dried, crushed and sieved through a 2 mm mesh before being analyzed for soil characteristics.

Chemical characteristics:
The pH and electrical conductivity (EC) of each sample were measured using a pH-meter and a conductivity meter in a 1:2.5 soil: water suspension, respectively. The organic matter (SOM) was determined by wet oxidation [22] and total Nitrogen (Nt) by the Kjeldhal method [23]. Moreover, extractable phosphorus (P) was quantified by Nelson method [24], exchangeable potassium K was extracted with 1 N ammonium acetate at pH 7 and quantified using atomic absorption spectrometer (Perkin Elmer 5100 PC).

Physical characteristics:
Soil water holding capacity and bulk density were at the beginning and at the end of the trials (November, 2009 and August 20012, respectively). The Bulk density (BD) was measured by the core method [25], using cores 3 cm in diameter, 10 cm in length and 70.65 cm3 in volume. Water holding capacity was measured by gravimetric method [26].

Biological characteristics:
Microbial populations and general microbial activity were measured in September 2012 at the end of the trial. Microbial populations were determined by soil dilution plating on various agar media [27]. Data was expressed as the number of colony forming units (CFU g^{-1} of dry soil, bacteria was expressed as x 10^5 CFU g^{-1} and fungi as x 10^7). General microbial activity was measured by hydrolysis of fluorescein diacetate (FDA) using the procedure of Adam and Duncan [28].

Data analysis

The analysis of variance was performed and completed by Student-Newman-Keuls test in case of significance at P≤5% using the Micro-Computer Program COSTAT [29].

Results

1) **The effect of the inclusion of vetch/barley and fodder pea/barley in the cropping systems on the soil physic-chemical characteristics**

Table 2: Effect of different rotations on the physic-chemical characteristics

	INRA Station		
	pH	**EC (mS/Cm)**	**OM (%)**
Barley-Maize	8.86(+4%) b	0.128(-12%)b	0.68(-31%)a
Maize monoculture	8.94(+5%) b	0.112(-23%) a	0.76(-22%)b
Vetch/barley-Maize	7.57(-11%) a	0.312(+54) cd	1.24(+21%)c
Fodder pea/barley-Maize	7.66(-10%) a	0.286(+49) c	1.22(+20%)c
Initial Value	8.50	0.145	0.98
	Tizi N'Test Site		
Barley-Maize	8.51(+4%)b	0.626(-30%)a	2.18(-22%)a
Maize monoculture	8.62(+6%)c	0.688(-36%)a	2.12(-24%)a
Vetch/barley-Maize	7.60(-7%)a	1.450(+32%)cd	3.56(+21%)b
Fodder pea/barley-Maize	7.69(-6%)a	1.356(+38%)c	3.44(+19%)b
Initial Value	8.14	0.98	2.80

a) Effect on soil pH

Initial hydrogen potential of soils are moderately to strongly basic and varies between 8.5 and 8.14 for the INRA station and the TiziN'Test Site, respectively. Barley-maize rotation and maize monoculture caused small increases each year of experimentation, but overall this elevation at the end of the third year became significant. Result of ANOVA (Table 2) showed tha the continuous maize had alkalinized soil pH by 5 and 6% (compared to the initial value), for INRA Station and Tizi N'Test Site, respectively. Barley-maize rotation had also alkalinized soil pH by 4% (compared to the initial value), for the two Experimental Station. Nevertheless, result of ANOVA (Table 2) showed that the inclusion in the maize rotation the vetch and the fodder pea mixed with barley had acidified significantly the soil pH. In the INRA Station, the pH value was decreased by 11 and 10% (compared to the initial value), for vetch/barley-maize and fodder pea/barley-maize rotations, respectively. There is no significant difference between vetch and fodder pea. In the Tizi N'Test Site, the pH value was decreased by 7 and 6% (compared to the initial value), for vetch/barley-maize and fodder pea/barley-maize rotations, respectively. In the two Experimental Sites, there is no significant difference between vetch/barley and fodder pea/barley. Legumes are known acquire their nitrogen from the air as diatomic nitrogen rather than from the soil as nitrate, their net effect is to lower the pH of the soil [30]. This soil acidification under legumes has been attributed to the release of protons (H+) during the oxidation of carbon and nitrogen compounds in soils [31][32]. Also, the accumulation of organic matter has been suggested to be one of the causes of soil acidification [33].

b) Effect on Electrical conductivity

According to the initial value (Table 2) we observe that the soil at the TiziN'Test site is more saline (0.98 mS/cm) than the INRA Station (0.15mS/cm). In the two experimental sites, EC was clearly influenced by cropping practices (Table 2). Table 2 showed that the inclusion in the corn rotation of the vetch-barley and fodder pea-barley salinized significantly the soil. There was a highly significant difference in terms of EC level variation between the two experimental sites for all rotation systems (Table 2). At the INRA Station, the last cropping cycle of vetch/barley-corn and fodder pea/barley-corn enhanced the EC value by 54 % and 49% respectively compared to the initial value. However, barley-corn and corn monoculture caused depletion on the EC value respectively by -12% and -23% compared to initial value. Regarding, TiziN'Test site, the last cropping cycle of vetch/barley-corn and fodder pea/barley-corn showed the highest EC level compared to initial value with 32 % and 38% respectively higher than in barley-corn -30% and corn monoculture -36%. For both experimental sites, there is no significant difference between vetch and fodder peas. This variability of EC it primarily attributed to the variation of the nitrate concentration in the soil. Mineral nitrogen in the root zone soil is often higher in cereal-legume cropping systems than cereal monocultures [34][35]. Increase in nitrogen has been attributed to both nitrate-sparing by the legumes [36] and mineralization of the N rich residues [36][37][38].

a) Effect on Organic matter

The initial rate of organic matter ranged from 0.98% to 2.8% respectively for the INRA station and the TiziN'Test site. Result of ANOVA (Table 2) showed that in the two experimental sites, there was a considerable effect of even maize-rotations on the residual soil organic matter (Table 2). In the INRA Station, soil organic matter had the highest value in vetch/barley-maize and pea fodder/barley-maize rotations, but the lowest in maize monoculture and barley (Table 2). It seems that introduction of vetch and fodder pea for three years in rotation with maize led to an increase in the concentration of soil organic matter, respectively of 21% and 20%. Nevertheless, maize monoculture and barley-maize rotation caused a high decrease in the concentration of soil organic matter, compared to the initial value, with -22% and -31%, respectively. The same trend was recorded in the TiziN'test site, vetch/barley-maize and fodder pea/barley-maize rotations had a positive effect on residual soil organic matter, but maize monoculture and barley-maize rotation affect it negatively. The maximum improvement compared to the initial value occurred for vetch/barley-maize rotation (21%) followed by fodder pea/barley-maize rotation (19%). There was a decrease in residual soil organic matter due to maize monoculture (-24%) and barley-maize rotation (-22%). In general, legume-based cropping systems, with their narrow carbon to nitrogen organic residues combined with the relatively greater temporal diversity in cropping sequences, significantly increased the retention of soil C and N. Rotations that include legumes can maintain higher organic matter levels than continuous cropping systems with non-leguminous crops [39]. [40] reported that wheat–lentil system had higher soil C levels than other wheat cropping systems and attributed the difference to more efficient conversion of residue C to soil C in legume rotation systems than in monoculture wheat.

2) The effect of the inclusion of vetch/barley and fodder pea/barley in the cropping systems on the soil chemical characteristics

Table 3: Effect of different rotations on the chemical characteristics

	INRA Station		
	TN (%)	P (mg/Kg)	K (mg/Kg)
Barley-Maize	0.043(-26%)a	12.42(-33%)ab	148(-23%)
Maize monoculture	0.042(-28%)a	11.96(-36%)a	160(-17%)
Vetch/barley-Maize	0.072(19%)bc	14.48(-1%)c	220(12%)
Fodder pea/barley-Maize	0.067(13%)b	26.48(-2%) cd	210(8%)
Initial Value	0.058	18.67	193
	Tizi N'Test Site		
Barley-Maize	0.090(-36%)a	19.11(-29%)a	324(-47%)
Maize monoculture	0.110(-21%)b	18.86(-30%)a	309(-49%)
Vetch/barley-Maize	0.184(+24%)c	28.10(+4%)b	676(10%)
Fodder pea/barley-Maize	0.176(+20%)c	35.59(-1.6%)b	648(6%)
Initial Value	0.140	26.92	607

a) Effect on residual soil nitrogen:

The initial soil total nitrogen content was ranged from 0.058 to 0.14 g/kg respectively for the INRA Station and TiziN'Test site. For both experimental sites (INRA Station and TiziN'Test), the Residual soil total nitrogen was depleted compared to the initial value in barley-maize rotation by -26 and -36%, respectively and continuous maize recorded -28 and -21%, respectively (Table 3). Residual soil total nitrogen was found improved in all the legumes mixed with barley and rotated with maize. Vetch/barley-maize rotation increased soil total nitrogen by 19 and 24% for INRA Station and Tizi N'Test Site, respectively. However, fodder pea/barley-maize rotation increased soil total nitrogen with 13 and 20% for the INRA Station and Tizi N'Test Site, respectively. In fact, the same finding was showed in several studies [41][42] and reported that soil N availability throughout the growing season was greater in the pea–wheat than in the wheat–wheat rotation. The ability of legumes to fix atmospheric nitrogen, their nodulated roots and plant residues left after harvesting represent a valuable source of organic N [43][18]. Nitrogen in the root zone soil is often higher in cereal–legume cropping systems than cereal monocultures [43][44]. Increase of Nitrogen has been attributed to both nitrate-sparing by the legume and mineralization of the N rich residues [42].

b) Effect on residual soil phosphorus

The initial soil total phosphorus content was ranged from 11.96 to 18.86 mg/kg for the INRA station and the TiziN'Test Site, respectively. At the INRA station, the residual soil extractable phosphorus decline was occurred by-36% for maize monoculture followed by barley-maize rotation (-33%). Vetch/barley-maize rotation and fodder pea/barley-maize rotation showed a low depletion of -1% and -2%, respectively (Table 3). At the Tizi N'Test Site, the residual soil extractable phosphorus decline was occurred for maize monoculture by -30% followed by barley-maize rotation with -29% and fodder pea/barley-maize rotation with a low depletion (-1.6%). However, vetch/barley-maize rotation showed a low increase (4%).This finding was attributed to uptake by the legumes after it became more available as a result of the rise in soil pH. Phosphorus is required for growth and development of legumes as it is critical for both number and density of nodules and nitrogen fixation [45].

c) Residual soil potassium (K2O)

The initial soil exchangeable potassium content was ranged from 193 to 607 mg/kg respectively for the INRA station and TiziN'Test site. At the INRA station, the residual soil extractable potassium decline for maize monoculture was -17% followed by barley-maize rotation (-23%). At the Tizi N'Test Site, the residual soil extractable potassium decline for maize monoculture was -49% followed by barley-maize rotation (-47%). Nevertheless, vetch/barley-maize rotation and fodder pea/barley-maize rotation recorded an increase of the residual soil extractable potassium (Table 3). At the INRA station, the residual soil extractable potassium increased for vetch/barley-maize rotation by 12% followed by fodder pea/barley-maize rotation (8%). The same finding was recorded at Tizi N'Test Site with an increase of 10% and 6% for vetch/barley-maize and the fodder pea/barley-maize rotation. At the end of the trial, the residual soil extractable potassium increased significantly ($P \leq 0.05$) in the soil which may be attributed to the release of nutrients after decomposition and mineralization of the legume's organic residues. Potassium is the second mineral element with a high concentration in plant parts after N that's why important amounts are added to the soil after organic residues decompose [46]. During mineralization of organic matter, a rapid release of K occurred and followed by slower releases of N, P and Ca [47]. However, the release of N, K and Ca is usually greater in legume litter due to tenderness of legume leaves compared to the slow release from grasses due to their higher lignification [48].

3) The effect of the inclusion of vetch/barley and fodder pea/barley in the cropping systems on the soil physical characteristics

Table 4: Effect of different rotations on the physical characteristics

	INRA Station	
	Bulk density (g/cm3)	Soil water holding capacity (%)
Barley-Maize	1.56(+7%) b	12.12 (-35%)b
Maize monoculture	1.52(+5%) b	11.96 (-36%)a
Vetch/barley-Maize	1.32(-9%) a	24.88 (+25)d
Fodder pea/barley-Maize	1.34(-8%) a	25.25 (+26)c
Initial Value	1.45	18.67
	Tizi N'Test Site	
Barley-Maize	1.45(+8%)b	0.63(-29%)a
Maize monoculture	1.40(+4%)c	0.69(-29%)ab
Vetch/barley-Maize	1.22(-9%)a	1.45(+23%)c
Fodder pea/barley-Maize	1.25(-7%)a	1.36(+24%)c
Initial Value	1.34	26.92

a) Bulk density (BD)

The initial soil bulk density (BD) was ranged from 1.45 to 1.34 g/cm3 for the INRA station and TiziN'Test site, respectively. Table 4 showed the effects of based-corn rotations on soil bulk density. At the INRA Station, barley-maize and maize monoculture increased bulk density compared to the initial value by 7 and 5%, respectively. Nevertheless, vetch/barley-maize and fodder pea/barley-maize rotations reduced soil bulk density by -9% and -8%, respectively. Relatively, the same trend was showed at the TiziN'Test site. This evolution of BD was attributed to the variation of the organic matter. Include legumes in the rotation crop system increase soil organic matter, improve soil porosity, reduce bulk density, recycle nutrients and improve soil structure [49]. Research in the United States and Canada reported that soil physical properties were improved after legumes cropping. A significant decrease in bulk density is probably related to greater amount of organic matter deposition and loosening of soil by root action [50][51]

b) Soil water holding capacity

Table 4 shows the results of soil water holding capacity (WHC). The initial value of WHC was ranged from 18.67 to 26.92 % at the INRA station and TiziN'Test site, respectively. At the INRA Station, barley-maize rotation and maize monoculture decreased significantly the WHC compared to the initial value by 36 and 35%, respectively. Nevertheless, vetch/barley-maize and fodder pea/barley-maize rotations increased the WHC by 25% and 26%, respectively. Similar trend was recorded for the TiziN'Test site. The barley-maize rotation and maize monoculture decreased significantly the WHC by 29%. However, vetch/barley-maize and fodder pea/barley-maize rotations increased the WHC by 23% and 24%, respectively. This evolution of WHC was definitely, attributed to the variation of the bulk density and the organic matter. [52] indicated that legume-wheat rotation has an important effect on residual soil moisture. On other hand, wheat-legume rotation was significantly more water use efficiency than wheat monoculture [53].

4) The effect of the inclusion of vetch/barley and fodder pea/barley in the cropping systems on the soil biological characteristics

Table 5: Effect of different rotations on the biological characteristics

	INRA Station	
	Total fungi (CFU g-1 dry soil)x10^7	Total bacteria (CFU g-1 dry soil)x10^5
Barley-Maize	18.34 ± 1,2 a	2.62 ± 0.08a
Maize monoculture	26.60 ± 0.8 b	2.96± 0.10 a
Vetch/barley-Maize	31.42 ± 1.4 c	10.98± 1.2 b
Fodder pea/barley-Maize	28.72 ± 1.6 c	11.25± 1.2 b
	Tizi N'Test Site	
Barley-Maize	20.62 ± 0,8 a	3.86 ± 0,2 a
Maize monoculture	29.86 ± 1.4 b	4.12 ± 0.4 a
Vetch/barley-Maize	37.94 ± 2.2 c	13.84± 1.3b
Fodder pea/barley-Maize	38.14 ± 2.0 c	14.10 ±1.2b

Table 5 showed clearly that the total flora was significantly lower in barley-maize rotation and Maize monoculture compared to the other rotations. Indeed, the total number of fungal recorded in barley-maize rotation was ranged from 18.34 to 20.62 CFU g-1 x 10^7 dry soil at INRA Station and Tizi N'Test Site, respectively. Moreover, the total number of fungi in maize monoculture soil was significantly a lowest than vetch/barley-maize and fodder pea/barley-maize rotations with 26.60 and 29.86 CFU g-1 x10^7dry soil for INRA Station and Tizi N'Test Site, respectively. Vetch/barley-maize and fodder pea/barley-maize rotations showed the similar total number of fungi in both experimental site and it was significantly the highest. At the INRA Station, total number of fungi was ranged from 28.72 to 31.42 CFU g-1 x 10^7 dry soil for fodder pea/barley-maize and vetch/barley-maize rotations, respectively. At the Tizi N'Test site, the total number of fungi was ranged from 37.94 to 38.14 CFU g-1 x 10^7 dry soil for fodder pea/barley-maize and vetch/barley-maize rotations, respectively.

For both experimental sites, the total number of bacteria was significantly lower in barley-maize rotation and maize monoculture, compared to the vetch/barley-maize and fodder pea/barley-maize rotations. There is no significant difference between barley-maize rotation and maize monoculture. Vetch/barley-maize and fodder pea/barley-maize rotations had a higher total number of bacteria. There is no significant difference between vetch and fodder pea. Several reported that crop rotation can stimulate soil biodiversity and biological activity through changes in the soil habitat studies [54], favoring the development of specific microbial communities [55]. Accordingly, because of the different quality and amount of exudates and organic components from root systems and crop residues, some groups of microorganisms can be differently influenced by crop sequence, supporting the results obtained in this work. Lower bulk density implies greater pore space and improved aeration, developing a suitable environment for biological activity [56]. Legumes could decrease the pH and promote increased plant-soil-microbial activity on soils with a pH above the range for optimum crop growth and development.

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Conclusion

In the Southwest of Morocco, rotations that include vetch and fodder pea mixed with barley can maintain higher organic matter and total nitrogen levels than corn continuous and barley-corn rotation. Other soil chemical properties, such as pH, may also be favorably affected by the cultivation of legumes. In addition to these characteristics that is added to the soil microbiological biomass, and soli water, as well as lower soil bulk density.

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