EFFECTS OF SULLA CROP (*Hedysarum coronarium* L.) CONDUCTED IN DIRECT AND CONVENTIONAL DRILLINGS, ON THE PHYSICO-CHEMICAL PROPERTIES OF CLAY SOIL UNDER TUNISIAN SEMI-ARID CLIMATE

BOUAJILA Khedija*, BEN JEDDI Faysal
The National Agronomic Institute of Tunis, Carthage University Tunisia
*E-mail: bouajilakhedija@yahoo.com

Abstract.-*The sulla crop (*Hedysarum Coronarium *L.) variety Bikra 21 was conducted in direct and conventional drillings, for treating the effects of this crop on some physicochemical properties of sloping land (6%). The experimental area is situated at Bou Salem (higher semi-arid) in the governorate of Jendouba (north-west of Tunisia). The organic sulla restitution has contributed to improve the contents of organic matter principally in layer. Indeed, the rates exceeded 3% in direct sowing as well as in the conventional one. However, the field in direct drilling was characterized by higher nitrogen contents (from 0.35 to 0.40 %). The presence of sulla improved soil structural stability (from 1.22 to 1.97 %) in direct drilling. Therefore, the cation exchange capacity was improved in layer, and was found better under the conditions of the direct drilling (from 60.2 to 65 meq/100g of soil) than in the conventional one (from 59 to 63.3 meq/100 g of soil). It should be noted that the presence of residues, especially on the surface supported the permeability of the ground, was mainly in direct drilling where the permeability was higher (17.83 cm/h in the surface of direct drilling versus 13.92 cm/h in the conventional one).*

Key words: *Sulla, organic matter, direct drilling, conventional drilling, clay soil*

EFFETS DU SULLA DU NORD (*Hedysarum coronarium* L.) CONDUITE EN SEMIS DIRECT ET CONVENTIONNEL SUR LES PROPRIETES PHYSICO-CHIMIQUES D UN SOL ARGILEUX SOUS CLIMAT SEMI-ARIDE TUNISIENNE

Résumé.- *Le sulla du nord (Hedysarum coronarium L.) variété Bikra 21 a été conduite en semis direct et conventionnel dans le but d'étudier les effets de cette culture de fabacées sur certaines propriétés physico-chimiques des terres en pente de 6% dans la région de Bou Salem appartenant au gouvernorat de Jendouba (nord-ouest de la Tunisie). Après une année de culture, les restitutions organiques ont contribué à améliorer les teneurs en matière organique principalement dans un horizon de 0-20 cm. En effet, les taux ont dépassé 3% aussi bien en semis direct que dans le conventionnel. Cependant, les parcelles conduites en semis direct se distinguent par des teneurs en azote supérieures, principalement dans la couche arable où les taux varient de 0.4 à 0.35%. La présence du sulla a amélioré la stabilité structurale du sol qui passe de 1.22 à 1.97% en semis direct et après une année de culture. En conséquence, la capacité d'échange cationique a été améliorée principalement en surface (0-20cm) et aussi bien dans les conditions du semis direct (de 60.2 à 65 méq/100g de sol) que dans le conventionnel (de 59 à 63.3 méq/100 g de sol). Il est à noter que la présence de résidus surtout en surface a favorisé la perméabilité du sol et ce principalement en semis direct où la perméabilité a été meilleure (17.83 cm/h en semis direct contre 13.92 cm/h en semis conventionnel).*

Mots-clés : *Sol, matière organique, semis direct, semis conventionnel, sol argileux,*

Introduction

Soil sensitivity to desertification and loss of productivity is due to a combination of natural and anthropogenic factors. The morphology of the field, soil type and rainfall aggressiveness are the principal pedoclimatic factors. Overexploitation of natural resources (land intensification, annual crop ...) and inappropriate farming techniques to local conditions (tillage in the direction of the slope, multiple interventions, inadequate rotations,…) have been implicated as factors aggravating the degradation of the situation [1]. All these factors expose the land to water erosion with significant loss of fertile land and an increased sensitivity to degradation [2] and therefore a negative impact on agricultural production and environmental quality [1].

In Tunisia, to maximize yields, farmers' practices were based on an energy tillage, non-judicious use of chemical fertilizers and phytosanitary treatments, taking the crop residues out of the plot ... In addition, the rotation of vegetable/wheat in four or three-year rotation in the north of Tunisia has declined sharply to represent only less than 6% in the Beja region [3].

And mineralization of organic matter is often compounded by a multiplication of the tillage operations, causing also a dilution of organic matter and an acceleration of the fermentation process. In fact, each year the equivalent of 5000 to 10,000 ha of land are lost [4]. Manure becomes a scarce and expensive commodity. The recycling of the fresh organic matter is virtually absent. The low content of organic matter reduces the retention capacity of water in the soil, favoring the adverse effects (temporary intra or inter seasonal) of drought and thus enables the erosion of fragile lands with a decrease fertility and hyper sensitivity to climatic irregularities [5].

In this context, RIO and LEPOIVRE (2003) [6], showed that the deep plowing increases and accelerates the process of mineralization in soil. In this case, the low content of organic matter present on the surface of the soil, increases sensitivity to rain splash and physical degradation.

To reduce the adverse effects of these farming systems currently practiced, it is necessary to carry out various farming techniques: The introduction of forage crops, especially Fabaceae, in culture systems that allow production of organic matter and nitrogen remaining in the soil at the end of the crop cycle. This wealth is regarded as an important criterion to define quality, fertility and the health of soil [5] and the choice of tillage methods which of better conserve the physico-chemical properties of the soil.

Sulla is an efficient plant genetic resource for forage production and valorization of degraded rangelands [5,7]. In addition, it protects the soil against the erosion [8] and contributes to their richness in organic nitrogen [5]. This specie is considered a protective and conservative culture of sloping mountain soils between 4 and 12% [8] Its root system can reach 2 m in depth, providing an appreciable amount of residue (between 5 and 15 t ha^{-1}) which can improve organic fertility in the soil [5,9]. Topping the rotation, a sulla in the 2nd year of culture provides nitrogen and organic matter respectively 226 kg ha^{-1} and 9.2 t ha^{-1} [5]. Moreover, in a sulla system, forage production is improved both in energy (22.6 to 34.5%) and protein (27-42%) compared to the conventional system of continuous wheat.

To preserve soil carbon, we must also adapt farming practices that maintain an adequate level of soil fertility. Less deep plowing (15-20 cm) or even direct drilling promote higher levels of organic matter in the topsoil due to the accumulation of crop residues on the surface.

LANGLET and RÉMY (1976) have shown that direct drilling and tillage have promoted a marked increase in levels of total nitrogen in the first centimeters of topsoil a strengthening of soil structure, protection against physical damage and improved microbial activity thanks to crop residues [10].

After several years of direct drilling, the upper soil layers become more stable and the rate of infiltration of water becomes faster than plowed surfaces [11].

SÉGUY et al. (2001) showed that in culture systems that lose organic matter (with tillage and monoculture), the trends in the cation exchange capacity CEC, strictly follow those of organic matter, CEC of surface horizons down. On the contrary, it increases in the same proportions by carrying out direct drilling [12].

It is in this context that we aim to study the impact of sulla (Bikra 21) conducted in direct drilling and conventional one, on the physico-chemical properties (organic carbon, total nitrogen, CEC, structural stability and permeability) of clay soil under Tunisian arid climate.

1.- Materials and Methods

1.1.- Pedo-climatic characteristics of the experimental site and plant material

The experimental site is located in the agricultural development farm in the north (Sedan), Bou Salem belonging to the governorate of Jendouba (North West of Tunisia) (figure 1). The station belongs to the upper semi-arid bioclimatic stage, characterized by a cold winter and a very dry and hot summer. The average annual rainfall over 50 years is estimated at 483 mm year^{-1}. The annual average temperature is about 37°C with average absolute maxima reaching 48°C and 49°C recorded in July and August which coincide with the appearance of siroccos. Absolute minima of - 5°C recorded between December and April.

The year of the trial (2004) was characterized by a cumulative rainfall estimated to 560 mm. Physical and chemical soil characteristics are shown in Table I.

The soil has a silty clay texture with rates of 23.3%; 59.2% and 17.5% respectively for clay, silt and sand. The organique carbone, total nitrogen and pH (H_2O) are respectively in the order of 1.43%; 0.21% and 7.98.

1.2. - Experimental set-up

To study the effect of these cultural practices (tillage, introduction of sulla North) in the culture system) on the improvement of soil properties and the fight against land degradation (water erosion), the tests were installed on a sloping plot (6%) with an area of 10 ha. The experimental plot is divided into two lots of 5 ha each one conducted by direct drilling (DD) or conventional one (CD). This parcel is located on slopes with a maximum of 6%. The upper part is much eroded with a very superficial soil (≤ 5 cm). The species used is sulla North Bikra 21 variety.

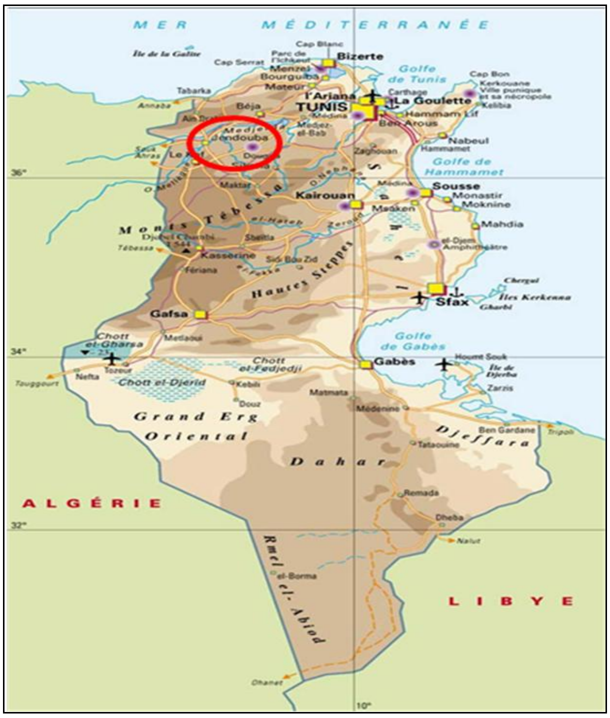

Figure 1.- Geographical location of the experimental site [13]

Table I .- Physical and chemical soil characteristics

Depth (cm)	Granulometry (%)			MO (%)	NT (%)	CEC (meq/100g)	Kech (mg/kg)	Passim (mg/kg)	pH
	Clay	Silty	Sand						
0-20	22,4 ± 1,27	57,45 ± 2,47	21,2 ± 5,23	2,58 ± 0,16	0,215 ± 0,01	59,5 ± 0,71	820 ± 14,14	25,83 ± 0,14	7,985 ± 0,01
20-40	23 ± 1,69	51,7 ± 0,424	25,25 ± 1,2	2,5 ± 0,071	0,195 ± 0,021	59,5 ± 0,283	727,5 ± 123,7	24,835 ± 1,181	7,995 ± 0,021
40-60	22,65 ± 0,21	53,7 ± 1,7	23,65 ± 1,95	2,13 ± 0,00	0,175 ± 0,01	57 ± 3,25	717,5 ± 137,89	19,5 ± 0,33	7,97 ± 0,01

Seedlings were done in the 31 October 2004 with a dose of 25 kg ha^{-1} of unhulled seed and an interline spacing of 75 cm [5]. Prior weeding (before drilling) at 2 liters / ha of glyphosate was carried out without any other treatment plant throughout the crop cycle.

Two campaigns of soil sampling were carried out: one before and one after planting the crop. Six soil samples were taken diagonally to each sub plot. Each sample is a repetition in the same sub plot.

Six samples of $1m^2$ sulla (each one weigh 500 g) per level (upstream and downstream) were collected at full bloom stage. Each sample is a repetition of the plant for the determination of total biomass harvested and for analysis of the plant.

Soil tests under question: the granulometry was conducted by the sedimentation method (pipette of Robinson-Kôhn), the organic material was conducted by the method of Walkley and Black, the total nitrogen content determined by the Kjeldahl method, the cation exchange capacity (CEC) using the method of percolation with ammonium acetate, the structural stability of the soil was measured in the laboratory by the method of [14]. The permeability test used to measure a rate of water infiltration (index k) by percolation through a sample of dried soil and sieved to 2 mm, under a constant load of water, which shows the resistance to the destruction of aggregates in a controlled infiltration [15].

1.3.- Statistical analysis of data

The data were subjected to analysis of variance (ANOVA) using SPSS (version 20) software. The Newman-Keuls test was used for comparison when the average of the significant differences between treatments was revealed a probability level of 5%.

2.- Results and Discussions

2.1.- Effects of tillage on physico-chemical characteristics of the soil

2.1.1.- Effect on the content of organic matter

The contents of organic matter, presented in Figure 2, showed that there is an increasing trend for both conventional and direct drillings.

Indeed, post-harvest and plot using conventional drilling, soil organic matter on the surface varies insignificantly from 3.01 to 3.09% and can reach 2.19% to 2.59 deep. While using direct drilling method, the content varies in surface from 3.06 to 3.11% and 2.35% to 3.09 deep. This shows that the simplification of work enriched the surface layers of soil organic matter soil. These results confirm the results of SÉGUY et al. (2001) [12]; CHERVET et al. (2001) [11]; LEPOIVRE RIO (2003) [6]. Furthermore, the presence of residues of culture sulla Bikra 21 has also enabled the enrichment of soil organic matter [5]. Thus, it can be concluded that there is a positive effect of tillage and cultivation of sulla Bikra 21 on the content of soil organic matter in the topsoil.

2.1.2.- Effect on the total nitrogen content of the soil

The total nitrogen content of the soil, shown in Figure 3, was significantly different in the plots in direct and conventional drilling of sulla, before drilling and after harvest. There is a tendency to increase in these levels as well as for conventional or direct drillings. This trend is more significant ($p < 0.05$) at the surface than at depth (20-40; 40-60 cm).

The increase of the total nitrogen in the case of a direct drilling is due to reduced tillage and the accumulation of nitrogenous material surface. These results confirm those of BOUHEJBA (1997) [16] and CHERVET et al. (2001) [11]. Indeed, previous studies have shown that the culture sulla Bikra 21 improves the soil organic nitrogen level. This species can return to the soil about 220 kg nitrogen / ha [17]. The arable soil horizon stores almost 50% of the total recovered. This result is correlated with root density of the species

[5].

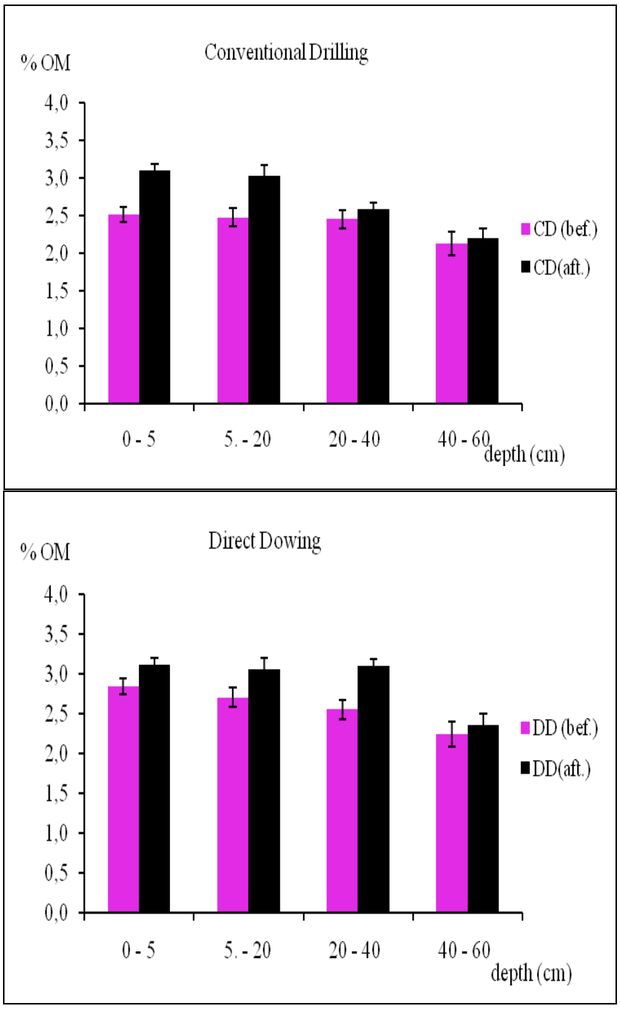

Figure 2.- Evolution of organic matter in plots of conventional and direct drilling of sulla. CD (bef.): conventional drilling plot (before drilling); CD (aft.): conventional drilling plot (after harvest); DD (bef.): direct drilling plot (before drilling); DD (aft.): direct drilling plot (after harvest).

This will further reduce the contribution of nitrogen fertilizer at least for the next grain [5]. This biological nitrogen (in the form of mineral nitrogen N-NO_3^- and N- NH_4^+) is released progressively from the mineralization of organic debris. Consequently, it prevents the action of nitrogen leaching often accentuated after a good rain [11].

2.1.3.- Effect on soil CEC

The results obtained in this work and presented in Figure 4, showed that there is a tendency to improve the Cation Exchange Capacity CEC for direct drilling. This trend follows strictly that of soil organic matter. It increases in the same proportions as organic matter when the rate of the latter increases in direct drilling systems.

In mode conventional tillage, CEC surface before planting varied insignificantly between 59 and 60 meq / 100 g soil. After harvest, we recorded 63.3 meq / 100 g of soil.

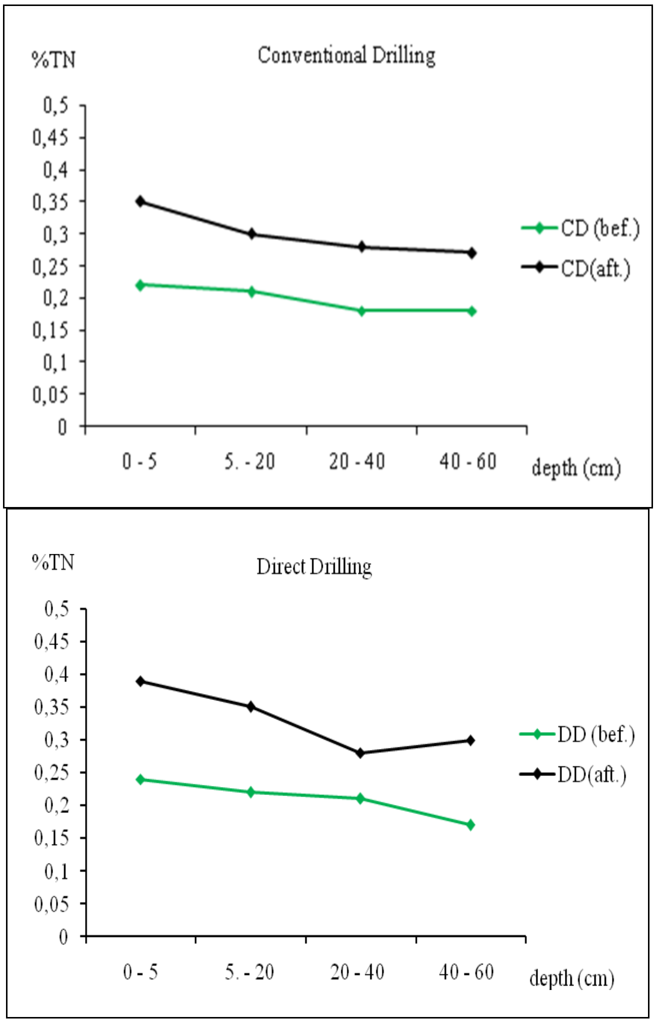

Figure 3.- Evolution of the total nitrogen content in the plots in direct and conventional drilling of sulla. CD (bef.): conventional drilling plot (before drilling); CD (aft.): conventional drilling plot (after harvest); DD (bef.): direct drilling plot (before drilling); DD (aft.): direct drilling plot (after harvest).

However, in plots managed in direct drilling and before planting, the CEC surface was approximately 60.3 meq/100 g of soil after harvest then, there has been a CEC value of the surface of the order of (64 to 65 meq/100 g of soil). This increase in CEC (about 6%) in the case of direct drilling is significant and is mainly due to the increase in organic matter content of the soil above the surface.

These results confirm those of SÉGUY et al. (2001) and BOUAJILA et al. (2014) [12,18].

2.1.4.- Effect on the structural stability

Our results concerning the evolution of the structural stability before planting and after harvest in plots led respectively by conventional tillage and drilling and presented in Figure 5, show an improvement of structural stability in the surface layer of the plot conducted in direct drilling compared to conventional planting. Indeed, the structural stability of the plot conducted in conventional planting was (0.95 - 1.13%) before seeding, but after harvest, it has improved to 1.87% (R^2 = 0.845).

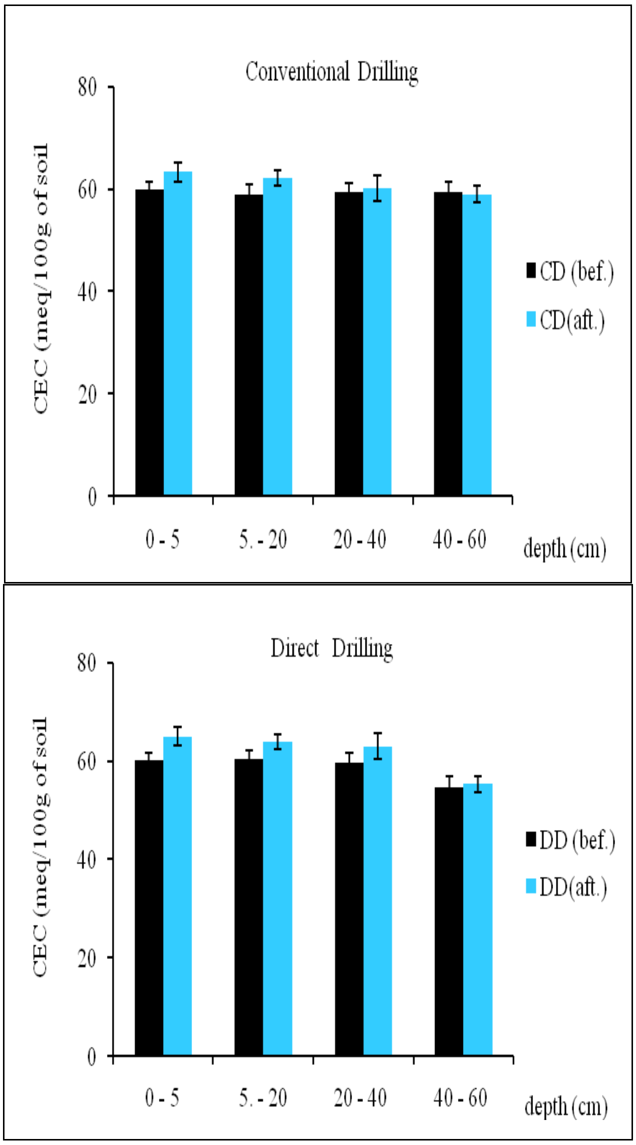

Figure 4.- Evolution of the Cation Exchange Capacity of the soil in the plots of conventional and direct drilling of sulla. CD(bef.): conventional drilling plot (before drilling); CD(aft.): conventional drilling plot (after harvest); DD(bef.): direct drilling plot (before drilling); DD (aft.): direct drilling plot (after harvest).

As direct drilling, it has better stability especially in surface and ranges from 1.15% to 1.23% before drilling and 1.22% to 1.97 after drilling (R^2 = 0.891). This result is significant and is due to the presence of a good organic content and a high microbial activity. Indeed, the organic material is a bonding agent and cohesion between the mineral soil particles [19], several studies have demonstrated the importance [20, 22].

MOLOPE and PAGE (1986), showed that during the intensification of farming practices and the cultivation of a field, there is usually a joint decrease in organic carbon content of soils and their stability structural [23]. On the other hand, reduced tillage or converting a plowed soil in prairie increases the amount of organic matter and soil structural stability.

In fact, the organic materials form an organo-mineral complex either directly by establishing connections between the positive and negative charges of the clay, or indirectly by cations such as iron (Fe) and aluminum (Al) [24].

In this work, we recorded, in depth of the two plots managed respectively by direct and conventional drillings, more or less important stability of 1.2%. This weakness can be tracked to the existence of a deep limestone crust. Limestone has an effect that is due primarily to the effect of Ca^{2+} ions; its contribution generally improves structural stability, however its action is significant only when the clay content is sufficient [25]. While the percentage of clay in depth in both plot, does not exceed 23%, which explains the weakness of the structural stability in depth.

We can therefore conclude that there is a positive effect on the surface of direct drilling and sulla residues on soil structural stability. These results are in agreement with those of [10,11;26,27].

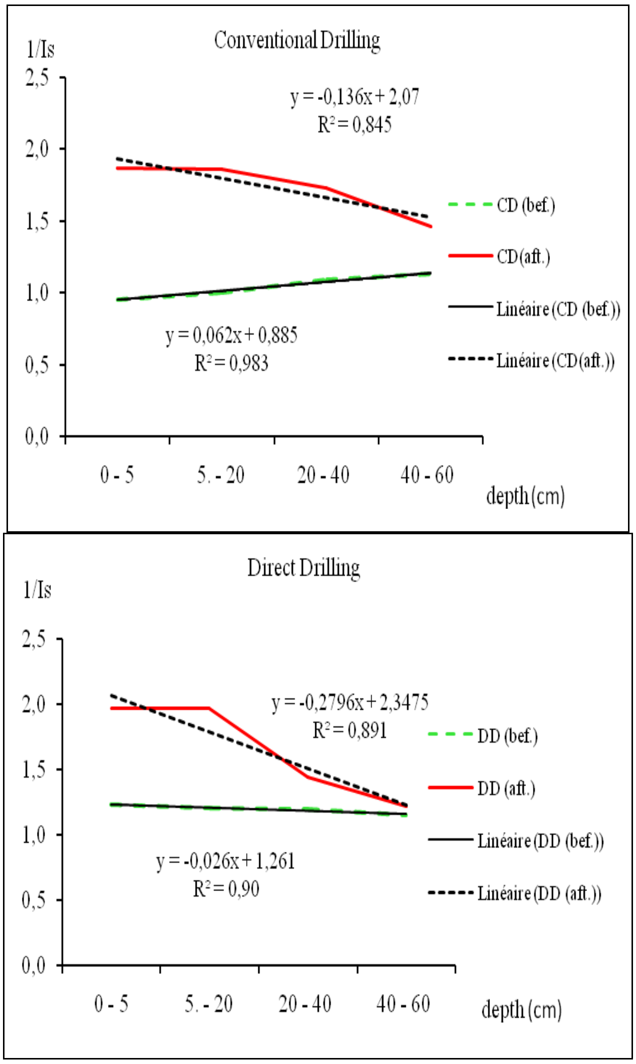

Figure 5.- Evolution of the structural stability of the soil in the plots of conventional and direct drilling of sulla. Is: index of instability; 1/Is: stability index, CD(bef.): conventional drilling plot (before drilling); CD(aft.): conventional drilling plot (after harvest); DD(bef.): direct drilling plot (before drilling); DD (aft.): direct drilling plot (after harvest).

2.1.5.- Effect on the water permeability of the soil

Monitoring of the evolution of permeability soil water before planting and after harvest in direct and conventional drillings plots and presented by the figure 6, shows that there is a trend towards improvement of this water permeability for the two cropping systems.

Before planting sulla, infiltration of water in surfaces conducted in direct drilling, varied insignificantly from 13.57 cm / h to 15.26 cm / h, it has improved after a year of sulla culture to reach 14.52 cm / h and 17.83 cm / h (R^2 = 0.966). In depth, infiltration is low in the order of 10 cm/h.

However, in conventional drilling, permeability did not exceed the 12.79 cm / h at the surface before planting, but after harvest there was permeability ranging between 11.17 and 13.92 cm. Direct drilling has therefore essential to halt the mixing of crop residue with deep horizons. Thus there is accumulation of organic material on the surface.

This increase in soil organic matter on the surface has positive effects on soil crusting [28]. In addition, the sulla Bikra 21 is a protective and conservative culture of the soil. With its deep taproot system (1.5 m to 2 m), it improves soil physical properties, such as infiltration of water [29]. This trend is more significant ($p < 0.05$) in conventional drilling depth where permeability changes from 5.2 to 9.8 cm / ha (R^2 = 0.845).

These results confirm those found by CHERVET et al. (2001) which showed that the rate of water infiltration, for surfaces in direct drilling is faster than the tilled surfaces [11]. As BOUHEJBA (1997) [15] showed that the minimum work reduces water loss when crop residues remain on the surface, evaporation is the main source of water loss from the soil.

2.2.- Forage productivity of Bikra 21

A wide production variability between and within plots was observed. The poor quality of the soil particularly upstream (sloping ground, stony and eroded) that forage productivity sulla was significantly reduced in conditions of direct drilling (table II).

Table II.- Variation of fresh forage yield of sulla (1st year) depending on the installation in conventional and direct drilling mode.Probability level of 5%, according to the Newman-Keuls test ($P < 0.05$).

Green matter yield (t ha^{-1})	Conventional Drilling	Direct Drilling
Upstream of the plot	4.5 – 18	2.5 – 3.5
Downstream of the plot	58 – 62	20 – 30
Average yield	33 ± 24.3	14 ± 12.4

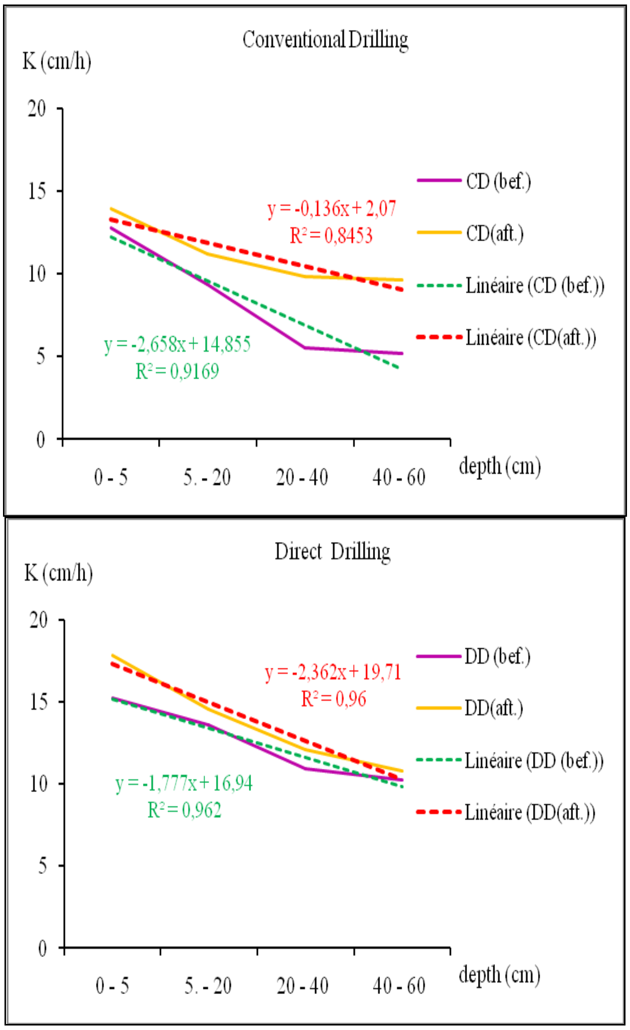

Figure 6.- Evolution of soil permeability in plots of conventional and direct drilling of sulla. K (cm / h): the water permeability of the soil in cm / h, CD(bef.): conventional drilling plot (before drilling); CD(aft.): conventional drilling plot (after harvest); DD(bef.): direct drilling plot (before drilling); DD (aft.): direct drilling plot (after harvest).

In the plot managed in conventional drilling the average yield of green matter was in the order of 33 ± 24.3 t ha^{-1}. The large observed standard deviation, explains the high heterogeneity of soil. Indeed, upstream soil is 6% slope; stony and eroded, downstream the soil is deep but with areas of low background and water stagnation (figure 7).

Whereas in direct drilling, the average yield was statistically significant ($P < 0.05$) lower in the order of 14 ± 12.4 t ha^{-1} of green matter, 43% of production in conventional drilling.

These results do not reflect the productive potential of Bikra 21 with a production of about 55 t / ha in the first year according to the description of the variety [5].

Failure to comply with the technical specifications of the variety is the main cause of this weakness in yield. The presence of a limestone crust very close to the surface (up to 50 cm) has also hampered the implementation of the culture of sulla.

In addition, a very important problem has been noticed in the first autumn rain (in October), it is the invasion of the plot by a very large population of snails from a nearby livestock. These snails have attacked the aerial part of the sulla plant to 1st leaf stadium and during the startup growth. The invasion began with the upstream part of the plot. Therefore, the damage has been very important in the direct drilling plot. This explains well the variation or weakness of production in this field.

Conclusion

The study of the practices impact on soil properties has enabled us to raise the following points:

Despite the short experience of direct drilling and very difficult experimental conditions of the plot allocated to Bikra 21culture for this work, the results of soil cover by plants are suitable (+ 80% coverage in conventional planting and + 60% coverage direct drilling).

The culture also enabled a very deep rooting up to 2 meters which improved the physical properties of the soil (increased infiltration of water, improving the capacity of retaining water..); and chemical properties of the soil (increasing the rate of organic matter biological nitrogen fixation, reduced nutrient leaching ...).

This plant has proved to be a good source of residues which constitute a mulch rich in nitrogen and organic material that protects the soil in slopes against erosion and improves fertility in minimizing the cost of production at the same time.

This mulch can also be a seedbed for next crop for a possible direct drilling. Improving organic matter, nitrogen, cation exchange capacity, structural stability and soil permeability after harvesting a crop sulla first year is a good sign for mainly marginal and slope soils. This was also observed in sulla direct drilling plots (3.1% of OM; 0.39% of TN; 65 meq/100g soil; Is= 1.9; 17.8 cm/h) rather than in the conventional one (3.0%OM; 0.35%TN; 63meq/100g soil; Is=1.8; 13.9 cm/h).

It remains to recheck the value of this cultural practice in conditions more favourable than those of the plot allocated to experimentation in work conditions.

Direct drilling of forage crops is a technique to make better use of the eroded and uneven land surface.

However, this technique can be effective only by the choice of appropriate species well playing the role of previous crops for strategic crops such as cereals. In this case, the sulla by its high organic refunds and its root system has improved some physicochemical parameters as a basis for better soil fertility.

References

[1].- Zouaghi M., 2004.- Techniques d'exploitation et de conservation du sulla Bikra 21. Ministère de l'Agriculture et de l'Environnement. Séminaire de formation, Zaghouan, Tunisie, 25p.

[2].- Sleutel S., De Neve S. and Hofmann G., 2003.- Estimates of carbon stock changes in Belgian cropland. Soil Use Manage, 19: 166-171.

[3].- Zouaghi M. et Tibaoui G., 1998.- Séminaire National sur le développement de la culture de sulla en Tunisie, Bizerte, 25p.

[4].- Mhiri A., 1999.- Problèmes et pratiques de lutte antiérosive en région méditerranéenne. In Rapports nationaux sur les problématiques et pratiques de lutte antiérosive. PAP/CAR – split, Tunisie, 162p.

[5].- Ben Jeddi F., 2005.- *Hedysarum coronarium* L.: variation génétique, création variétale et utilisation dans des rotations tunisiennes. Thèse de Doctorat en Sciences Biologiques Appliquées, option sciences agronomiques, Université de Gent, Faculté des Sciences en Bio-ingénierie, 203p.

[6].- Rio A. et Lepoivre M., 2003.- Bretagne environnement: Les sols bretons: une source ou un piège à carbone pour l'ammophile ? http://www.bretagneenvironnement.org/sols/rubrique400/article1036076744

[7].- Trifi-Farah N., Baatout H., Boussaïd M., 2002.- Evaluation des ressources génétiques des espéces du genre Hédysarum dans le bassin méditerranéen. Plant Gen. Res. Newsl., 130: 1-6.

[8].- Slim S. et Ben Jeddi F., 2011.- Protection des sols des zones montagneuses de la Tunisie par le sulla du Nord (*Hedysarum coronarium*L.). Revue Sécheresse, 22: 1- 8.

[9].- Ben Jeddi, F., Sanaa, M., Behaeghe, T., 1998.- Contribution des légumineuses fourragères à l'amélioration de la réserve humique du sol. Revue de l'INAT, 13: 95-109.

[10].- Langlet B. et Rémy J. C., 1976.- Incidence de la simplification du travail du sol sur la dynamique de l'azote. Simplification du travail du sol en production céréalière. ITCF, 189-204.

[11].- Chervet A., H. Reinhard H. et Sturny W. J., 2001.- Semis direct en grandes cultures. Revue suisse d'agriculture, 33: 15-24.

[12].- Séguy L., Bouzinac S., Maronezzi A.C., 2001.- Systèmes de culture et dynamique de la matière organique – Doc. CIRAD, Montpellier, France, 200p.

[13].- carte de la Tunisie : carte générale, http://www.lexilogos.com/tunisie_carte.htm.

[14].- Hénin S., Monnier G., Combeau A., 1958.- Méthode pour l'étude de la stabilité structurale des sols. Annales agronomiques, 9: 73-92.

[15].- Monnier G., 1994.- Assemblage et organisation physique des particules. In Bonneau M., Souchier B., Pedologie 2, Constituants et propriétés du sol, 2e édition. Ed. Masson, Paris-Madrid-Barcelone, 665p.

[16].- Bouhejba A., 1997.- Etude comparative des effets des différents modes de travail du sol sous des conditions semi-arides sur l'élaboration du rendement du blé tendre

(variété Salammbô 80). Mémoire de fin d'étude de cycle de spécialisation de l'INA Tunisie, 82p.

[17].- Ben Jeddi F., 2004.- Présentation des caractéristiques biologiques et agronomiques du Sulla du nord Bikra 21. Sidi Thabet, Tunisie, 34p.

[18].- Bouajila K., Ben Jeddi F., Taamallah H., Jedidi N., Sanaa M., 2014.- Effets de la composition chimique et biochimique des résidus de cultures sur leur décomposition dans un sol Limono-Argileux du semi aride. J. Mater. Environ. Sci., 5 (1): 159-166.

[19].- Chenu C., 1989.- Influence of a fungal polysaccharide, scleroglucan, on clay microstructures. Soil. Biol. Biochem., 21: 299-305.

[20].- Tisdall J. M., Oades J. M., 1982.- Organic matter and water- stable aggregates. Soils. J. Soil. sci., 33: 141-163.

[21].- Mustin M., 1987.- Le compost, gestion de la matière organique. Ed. Francois Dubusc, Paris, 670 p.

[22].- Le Bissonnais Y., Arrouays D., 1997.- Aggregate stability and assessment of soil crutability and erodibility. II. Application to humic loamy soils with various organic carbon contents. Eur. J. Soil. Sci., 48: 39-48.

[23].- Molope, M. B. and Page, E. R., 1986.- The contributions of fungi, bacteria and physical processes in the development of aggregate stability of a cultivated soil. In: J. M. Lopez-Real and R. D. Hodges (editors), The Role of Microorganisms in a Sustainable Agriculture. A. B. Academic Publishers, Berkhamstead, UK.

[24].- Bonneau J. M., Souchier B., 1979.- Constituants et propriétés du sol. Tome 2, Ed Masson, 459p.

[25].- Abiven S., 2004.- Relation entre caractéristiques des matières organiques apportées, dynamique de leur décomposition et évolution de la stabilité structurale du sol. Thèse de Doctorat de l'Ecole nationale Supérieure d'Agronomie de Rennes, France, 262p.

[26].- Manichon H., 1982.- Influence des systèmes de culture sur le profil cultural: élaboration d'une méthode de diagnostic basée sur l'observation morphologique. Thèse de docteur-ingénieur de l'INAPG, 232p.

[27].- Recous, S., Richard, G., Fruit, L., et Guerif, 2001.- Effect of contact between straw particles and soil on the short-term mineralization of C. European Journal of Soil Science.

[28].- Bouchendira M., 1989.- Effets des travaux du sol sur quelques caractéristiques du sol et de la plante. Revue de l'I.N.A.T., 4: 17-27.

[29].- Slim S., 2004. Amélioration fourragère et protection des terres par le Sulla Bikra 21 dans les gouvernorats de Zaghouan et de Siliana. Mémoire de Mastère de l'INA, Tunisie, 86p.