

# EFFECT OF CONSERVATION TILLAGE ON THE **SILTY-CLAY-LOAM** SOIL PHYSICAL AND MECHANICAL PROPERTIES

## ABSTRACT

Effect of different tillage methods on **silty-clay-loam** soil physical and mechanical properties was evaluated in **corn-wheat system during 2011 in Fars province, Iran**. Field test was conducted in the form of a split plot experiment with two factors (tillage methods and soil depth) and six replications for soil bulk density and penetration resistance. Main plots were tillage methods including conventional tillage, reduced tillage, and zero tillage. Soil depth ranges of **0-10, 10-20, and 20-30 cm** were considered as sub plots. A **randomized complete block design with three treatments and six replications** was used for the soil coefficients of **friction, adhesion, and cohesion**. Soil bulk density, soil penetration resistance, coefficients of soil internal and external friction, adhesion, and cohesion were measured. Results showed that tillage methods had significant effect on the soil bulk density so that the conventional and reduced tillage methods had the lowest soil bulk density, and zero tillage method had the highest. Soil bulk density was also affected by soil depth in such a way that bulk density increased when soil depth increased from **0 to 20 cm**, and then decreased by increasing soil depth from 20 to 30 cm. The maximum soil penetration resistance was **recorded** from the zero tillage, and the conventional tillage had the minimum soil penetration resistance. Soil penetration resistance increased with increasing soil depth from **0 to 30 cm**. Results also indicated that zero tillage significantly decreased the coefficient of soil internal friction; whereas, the coefficient of soil external friction was not affected by tillage methods.

**Keywords:** Bulk density; Friction coefficient; Penetration resistance; Tillage methods

## INTRODUCTION

Conventional tillage system is being replaced in the world by the conservation tillage method in which at least 30% of soil surface remains covered by crop residues (Afzalinia et al., 2012). Transition from the conventional tillage method to the conservation system may affect the soil physical and mechanical properties such as soil bulk density, soil penetration resistance, and soil internal and external coefficients of friction. Soil bulk density and penetration resistance are used as indices of soil compaction so that by increasing these two indices, soil compaction increases and increasing soil compaction may prevent water and crop root penetration in the soil. Soil bulk density and penetration resistance are also used to predict the depth of soil hardpan (Mehari et al., 2005). There are some contradictory results of research work conducted on the effect of conservation tillage on the soil bulk density and penetration resistance. Results of some studies show that conservation tillage methods (no-till and reduced tillage) increase the soil bulk density and penetration resistance compared to the conventional tillage (Liu et al., 2005; Taser and Metinoglu, 2005). Fabrizzi et al. (2005) evaluated the effect of conservation tillage on the soil temperature, compaction, water content, and crop yield and reported that soil had higher water retention during the critical growth stage of corn in no-till method. Their results also showed that no-till had the higher soil bulk density and penetration resistance, and lower soil temperature and corn yield compared to the minimum tillage method.

There are also some research results showing no significant effect of conservation tillage on the soil bulk density and penetration resistance (Rasouli et al., 2012; Afzalinia et al., 2012; Logsdon and Karlen, 2004). Touchton et al. (1984) reported that the winter legumes made no considerable variations in the soil nitrogen and bulk density, but increased the water infiltration rate when cotton was no-till planted into winter legumes compared to the cotton

48 direct seeding in the fallowed soil. Soil bulk density and penetration resistance are also  
49 affected by soil depth. Results of a research work in a Rhodic Ferrasol in Parana, Brazil,  
50 revealed that soil bulk density had the highest value at the soil depth range of 20 to 30 cm in a  
51 no-till system (Cavaliere et al., 2009). According to the results of a study conducted in  
52 Argentina, no-till increased soil resistance compared to the conventional tillage and soil  
53 resistance increment was greater in the shallow layers compared to the deep layers (Ferrerias et  
54 al., 2000). Results of a study conducted in Kimberly, Idaho showed that soil bulk density was  
55 16% to 18% greater in disk and no-till treatments compared to paratill in the soil depth range  
56 of 15 to 20 cm (Aase et al., 2001). Results of this investigation also indicated that there was a  
57 linear relationship between soil bulk density and soil penetration resistance. On the other hand,  
58 coefficients of friction between soil-soil particles and soil-steel surface can directly affect soil  
59 engaging tools wear and draft. Soil texture and structure have significant effect on the soil  
60 coefficient of friction (Manuwa, 2012). There is a correlation between angle of soil internal  
61 friction and soil bulk density in such a way that angle of soil internal friction is a quadratic  
62 function of soil bulk density (Ngapgue et al., 2012). Tillage methods may affect soil structure,  
63 which in turn affects soil coefficients of friction, adhesion, and cohesion; however, no research  
64 work regarding the effect of conservation tillage on the soil coefficients of friction, adhesion,  
65 and cohesion was found in the previous literature. Objective of this study was to determine the  
66 effect of conservation tillage and soil depth on the soil physical and mechanical properties  
67 such as bulk density, penetration resistance, and soil coefficients of friction, adhesion, and  
68 cohesion.

## 69 MATERIALS AND METHODS

70 This filed experiment was conducted at a farm in Fars province, Iran with the silty-  
71 clay-loam soil having acidity of 8.4 and electrical conductivity of 079 dS m<sup>-1</sup> (Table 1). The

72 trial was conducted in the form of a randomized complete block design with three treatments  
 73 and six replications for the soil coefficients of friction, adhesion, and cohesion. For soil bulk  
 74 density and soil penetration resistance, a split plot experiment with the base of randomized  
 75 complete block

76 **Table 1.** Soil specifications of the experimental area in the farm.

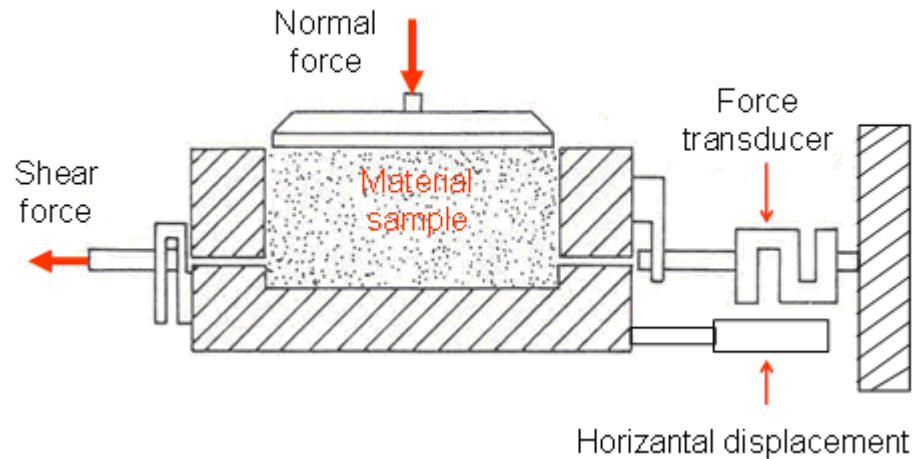
pH	EC (dS m <sup>-1</sup> )	Silt (%)	Clay (%)	Sand (%)	Soil texture
8.4	0.79	54.73	40.94	4.33	Silty clay loam

77

78 design with two factors (tillage methods and soil depth) and six replications was used. In the  
 79 main plots, three tillage methods such as conventional tillage (CT), reduced tillage (RT), zero  
 80 tillage (ZT), and in sub-plots three soil depths such as 0 to 10, 10-20, 20-30 cm were  
 81 evaluated. In the conventional tillage method, primary tillage was performed using a  
 82 moldboard plow with working depth of 25 cm, and disk harrow and land leveler were used as  
 83 the secondary tillage implements. A tine and disc cultivator, which was able to complete the  
 84 primary and secondary tillage operations simultaneously, was used to prepare seed bed in the  
 85 reduced tillage method (with working depth of 15 cm). BERTINI pneumatic direct planter  
 86 (Rosario, Santa Fe, Argentina) was utilized to plant corn seed directly (planting depth of 5 cm)  
 87 without any seed bed preparation in the no-tillage method. Standing crop residue was kept in  
 88 the plots for all tillage treatments. Corn (*Zea mays* L., single cross 704) at the seed rate of 25  
 89 kg ha<sup>-1</sup> and the row space of 75 cm was planted in 20mx6m plots. Sprinkle irrigation system  
 90 was used to irrigate the experimental plots of all treatments. Tillage treatments were applied  
 91 for two years (2009-2011) in irrigated corn-wheat rotation.

92 Soil bulk density, soil penetration resistance (PR), soil internal coefficient of friction  
93 (coefficient of friction between soil particles), soil external coefficient of friction (coefficient  
94 of friction between soil and steel surface), adhesion coefficient, and cohesion coefficient were  
95 measured in September, 2011 at the harvest of corn crop. Collected data were analyzed (one  
96 way ANOVA) using SAS statistics software and Duncan's multiple range tests were used to  
97 compare the treatments means. Soil bulk density was measured at the soil depths of 0-10, 10-  
98 20, and 20-30 cm using core samplers. Samples were taken from three different locations of  
99 each plot and dried at 105 °C for 24 hours.

100 Soil penetration resistance was measured using a cone soil penetrometer (Eijkelkamp  
101 6.15 with cone diameter of 11.28 mm and penetration rate of 2 cm s<sup>-1</sup>) up to the soil depth of  
102 30 cm with 10 cm depth interval at the moisture content of 23% w.b. (field capacity). Average  
103 of 10 penetrations at each soil depth range was considered as the soil penetration resistance of  
104 each plot. Soil coefficient of internal friction and the coefficient of soil friction on a polished  
105 steel surface were determined in the laboratory using a shear box apparatus (Fig. 1). This  
106 apparatus consisted of a sample box (6cmx6cm) for holding the soil samples, a force  
107 transducer to record the frictional force, a linkage to apply the normal force to the sample, and  
108 an electrical motor to provide a relative motion for the variable half of the sample box with  
109 respect to its fixed half. Both coefficients were determined at the average soil moisture content  
110 of 18% (wb) and tests were carried out at three levels of normal pressures (100, 200, and 300  
111 kPa). For each test, soil sample was put in the sample box and the bottom half of the sample  
112 box was subjected to a shear force by the electrical motor at a shear rate of 0.5 mm min<sup>-1</sup>  
113 for each of the aforementioned normal pressures. The frictional forces and horizontal  
114 displacements were recorded by the shear box during the test running period.



115

116

Fig. 1. Schematic of shear box apparatus.

117

118

119

120

121

122

123

124

Each test was repeated six times, and a new sample was used for each test. In the case of surface friction measurements, the steel surface was cleaned after running each test to remove the residue deposited on the surface. The maximum shear stresses were plotted versus the normal pressures for each replication. The slope of the best fit line to the plotted data was considered as the coefficient of friction of the sample at that replication based on Mohr-Coulomb's model. Mohr-Coulomb's model expresses shear stress as a function of normal stress, coefficient of friction, and adhesion or cohesion coefficients as follows (Lawton and Marchant, 1980):

125

$$\tau = C_a + \mu\sigma_n, \quad (1)$$

126

where:

127

$\tau$  = effective shear stress (kPa),

128

$C_a$  = adhesion coefficient (kPa),

129

$\mu$  = coefficient of external friction (decimal) and

130

$\sigma_n$  = effective normal stress (kPa).

131 In the coefficient of internal friction measurement, the y-intercept represents the cohesion  
 132 coefficient (it is shown by C) and  $\mu$  is the coefficient of internal friction.

133

## 134 RESULTS AND DISCUSSION

135 Results showed that tillage method ( $p < 0.05$ ) and soil depth ( $p < 0.01$ ) had significant  
 136 effect on the soil bulk density; while, this parameter was not affected by interaction **effect of**  
 137 tillage method and soil depth (Table 2). Soil disturbance intensity **was** different in various  
 138 tillage methods; therefore, significant effect of tillage method on the soil bulk density **was**  
 139 expected.

140 **Table 2.** Variance analysis of soil bulk density data.

Variation source	Degree of freedom	Sum squares	Mean squares	F values
Tillage method	2	0.027	0.014	9.08*
Soil depth	2	0.146	0.073	48.51**
Interaction between tillage method and soil depth	4	0.005	0.001	0.86 <sup>ns</sup>
Error	30	0.03	0.002	-

141 <sup>ns</sup>: **Non-significant**; \* : significant at  $p < 0.05$ ; \*\* : significant at  $p < 0.01$ .

142

143 The maximum soil bulk density was related to the zero tillage method which was  
 144 significantly different from those of the reduced and conventional tillage methods (Table 3).  
 145 The conventional and reduced tillage methods had identical soil bulk density. The higher soil  
 146 bulk density in zero tillage was associated with the lack of soil disturbance in this tillage  
 147 method. **The similar results were also reported by Liu et al. (2005), Taser and Metinoglu**

148 (2005), Fabrizzi et al. (2005), and Afzalinea and Zabihi (2014). Soil bulk density increased  
 149 with increasing soil depth from 0 to 20 cm and then decreased when the soil depth increased  
 150 from 20 to 30 cm; therefore, the maximum soil bulk density was occurred at the soil depth  
 151 range of 10 to 20 cm (Table 3). Reason for occurring the maximum soil bulk density at 10 to  
 152 20 cm soil depth was probably concentration of the pressure applied to the soil by agricultural  
 153 machinery traffics at this soil depth. Increasing soil bulk density from the soil surface to a  
 154 certain depth and its decreasing after that depth, has been also reported by Cavalieri et al.  
 155 (2009).

156 **Table 3.** Average soil bulk density under different tillage methods and at different soil depths.

Tillage method	Bulk density (Mg m <sup>-3</sup> )	Soil depth (mm)	Bulk density (Mg m <sup>-3</sup> )
Conventional tillage	1.22 b	0-100	1.24b
Reduced tillage	1.22 b	100-200	1.29 a
Zero tillage	1.26 a	200-300	1.16 c

157 a, b, c: averages with different letters in each column and group are statistically different at  
 158 p<0.05.

159 Results of penetration resistance data analyses indicated that soil penetration resistance  
 160 was significantly (p<0.01) affected by tillage methods, soil depth, and interaction between  
 161 tillage method and soil depth (Table 4). The reason for the soil penetration resistance being  
 162 significantly affected by the tillage methods and soil depth was diversity of soil disturbance  
 163 intensity in various tillage methods and soil depths.

164

165

166



167 **Table 4.** Variance analysis of soil penetration resistance data.

Variation source	Degree of freedom	Sum squares	Mean squares	F value
Tillage method	2	2.36	1.18	117.33 <sup>**</sup>
Soil depth	2	1.43	0.72	71.11 <sup>**</sup>
Interaction between tillage method and soil depth	4	0.36	0.09	8.85 <sup>**</sup>
Error	30	0.28	0.009	-

168 <sup>\*\*</sup>: significant at  $p < 0.01$

169 Soil penetration resistance means comparison revealed that the maximum soil  
 170 penetration resistance was occurred in the zero tillage because of the minimum soil  
 171 disturbance in this method and the minimum amount of penetration resistance was related to  
 172 the conventional method due to the maximum soil disturbance in this tillage treatment (Table  
 173 5). The higher soil penetration resistance (higher soil compaction) in the zero tillage method  
 174 can reduce water infiltration and crop root penetration in the soil. Liu et al. (2005), Taser and  
 175 Metinoglu (2005), and Fabrizzi et al. (2005) also reported a higher soil penetration resistance  
 176 for the zero tillage compared to the conventional method. Soil penetration resistance increased  
 177 when the soil depth increased from 0 to 30 cm so that the soil depth range of 20 to 30 cm had  
 178 the highest soil penetration resistance, and the soil depth range of 0 to 10 cm had the lowest  
 179 one (Table 5). The interaction effect of tillage methods and soil depth on the soil penetration  
 180 resistance showed that there was a significant difference between tillage methods at all the soil  
 181 depths (Table 6). Conventional tillage method at the soil depth range of 0 to 10 cm had the  
 182 lowest soil penetration resistance and zero tillage at the soil depth range of 20 to 30 cm had the

183 highest penetration resistance. The difference between cone indices of tillage methods  
 184 increased with increasing soil depth so that the difference was the least at the soil depth range  
 185 of 0 to 10 cm and was the most at the soil depth range of 20 to 30 cm. Although zero tillage  
 186 method had the maximum value of soil penetration resistance, but it was lower than the critical  
 187 soil penetration resistance for agricultural crops (about 2 MPa).

188

189 **Table 5.** Average soil penetration resistance under different tillage methods and at different  
 190 soil depths.

Tillage method	Penetration resistance (MPa)	Soil depth (cm)	Penetration resistance (MPa)
Conventional tillage	0.48 c	0-100	0.55 c
Reduced tillage	0.78 b	100-200	0.76 b
Zero tillage	0.99 a	200-300	0.94 a

191 a, b, c: averages with different letters in each column and group are statistically different at  
 192  $p < 0.05$ .

193 **Table 6.** Interaction effect of tillage methods and soil depths on soil penetration resistance.

Tillage method	Soil depth (cm)	Penetration resistance (MPa)
Conventional tillage	0-10	0.40 e
Conventional tillage	10-20	0.46 e
Conventional tillage	20-30	0.57 d
Reduced tillage	0-10	0.46 e
Reduced tillage	10-20	0.78 c
Reduced tillage	20-30	1.10 ab
Zero tillage	0-10	0.77 c

Zero tillage	10-20	1.02 b
Zero tillage	20-30	1.16 a

194 a, b, c, d, e: averages with different letters in each column and group are statistically different  
 195 at p<0.05.

196 Data analysis of coefficients of soil internal friction, external friction, cohesion, and  
 197 adhesion indicated that coefficient of soil internal friction and adhesion coefficient were  
 198 significantly affected (p<0.05) by tillage methods; while, the effect of tillage treatments on the  
 199 coefficient of soil external friction and cohesion coefficient was not statistically significant  
 200 (Table 7).

201 **Table 7.** Variance analysis of coefficients of soil internal friction, external friction, cohesion,  
 202 and adhesion (F values).

Variation source	Internal friction	External friction	Cohesion	Adhesion
Replication	0.85 <sup>ns</sup>	0.68 <sup>ns</sup>	1.59 <sup>ns</sup>	6.84 <sup>*</sup>
Tillage method	3.23 <sup>*</sup>	0.14 <sup>ns</sup>	1.85 <sup>*</sup>	3.45 <sup>*</sup>

203 <sup>ns</sup>: non-significant; <sup>\*</sup>: significant at p<0.05.

204 Coefficients of soil internal friction and cohesion in different tillage methods are  
 205 shown in table 8. Reduced and conventional tillage methods had the highest coefficient of  
 206 internal friction; whereas, the lowest coefficient of internal friction was obtained from the zero  
 207 tillage. Reduction of soil coefficient of internal friction in the zero tillage method was  
 208 probably because of improving soil structure in this tillage system. Since soil specific  
 209 resistance was significantly influenced by the soil coefficient of internal friction, zero tillage  
 210 method can reduce soil specific resistance by reducing the coefficient of internal friction. The  
 211 maximum cohesion coefficient was related to the zero tillage method, which was statistically

212 different from those of the conventional and reduced tillage treatments. The minimum  
 213 cohesion coefficient was obtained from the reduced tillage method (Table 8).

214

215 **Table 8.** Average coefficients of soil internal friction and cohesion in different tillage  
 216 methods.

Tillage method	Coefficient of internal friction	Cohesion coefficient (kPa)
Conventional tillage	0.44 a	13.2 b
Reduced tillage	0.45 a	10.5 b
Zero tillage	0.35 b	21.0 a

217 a, b: averages with different letters in each column and group are statistically different at  
 218  $p < 0.05$ .

219 There was not a significant difference between tillage treatments for coefficient of soil  
 220 external friction (Table 9). **However**, this coefficient had slightly higher amount in the **reduced**  
 221 tillage method compared to the conventional and **zero** tillage treatments. Results of this study  
 222 also showed that the difference between the tillage methods for adhesion coefficient was  
 223 significant in such a way that the largest amount of soil adhesion coefficient was obtained  
 224 from the zero tillage and the smallest one was related to the reduced tillage method.

225

226 **Table 9.** Average coefficients of soil external friction and adhesion in different tillage  
 227 methods.

Tillage method	Coefficient of external friction	Adhesion coefficient (kPa)
Conventional tillage	0.27 a	15.5 b
Reduced tillage	0.30 a	9.6 c

---

Zero tillage	0.27 a	18.1 a
--------------	--------	--------

---

228 a, b, c: averages with different letters in each column and group are statistically different at  
229  $p < 0.05$ .

### 230 CONCLUSIONS

231 It can be concluded from the results of this investigation that zero tillage method had  
232 the maximum soil bulk density and penetration resistance, and conventional tillage treatment  
233 had the minimum soil bulk density and penetration resistance. Penetration resistance increased  
234 with increasing soil depth from 0 to 30 cm; whereas, bulk density increased when soil depth  
235 increased from 0 to 20 cm and then decreased with increasing soil depth from 20 to 30 cm. It  
236 was also observed that tillage method had a significant effect on the coefficient of soil internal  
237 friction and adhesion coefficient; while, the coefficient of soil external friction and cohesion  
238 coefficient were not significantly affected by the tillage treatments. The zero tillage method  
239 reduces the coefficient of soil internal friction which may in turn reduce the soil specific  
240 resistance and power required to cultivate the soil.

### 241 RECOMMENDATION FOR FUTURE WORK

242 According to results and limitations of this study, the following recommendation can be  
243 given to make the future studies more effective in this area. Since the coefficients of soil  
244 friction were measured at one level of moisture content in the present study, the interactive  
245 effect of soil moisture content and tillage methods on the coefficients of soil internal and  
246 external friction, adhesion, and cohesion may be evaluated in the future research.

### 247 REFERENCES

- 248 1. Aase JK, Bjerneberg DL, Sojka RE. 2001 Zone-Subsoiling Relationships to Bulk  
249 Density and Cone index on a Furrow-Irrigated Soil. *Transactions of the ASAE*, 44,  
250 577-583.
- 251 2. Afzalinea S, Karami A, Alavimanesh SM. 2012. Comparing Conservation and  
252 Conventional Tillage Methods in Corn-Wheat Rotation. *Paper presented at the*  
253 *International Conference of Agricultural Engineering, Valencia, Spain*, 8-12 July  
254 2012.
- 255 3. Afzalinea S, Zabihi, J. 2014. Soil compaction variation during corn growing season  
256 under conservation tillage. *Soil Tillage Research*, 137, 1-6.
- 257 4. Fabrizio KP, Garc´ FO, Costa JL, Picone LI. 2005. Soil Water Dynamics, Physical  
258 Properties and Corn and Wheat Responses to Minimum and No-tillage Systems in the  
259 Southern Pampas of Argentina. *Soil Tillage Research*, 81, 57-69.
- 260 5. Ferreras LA, Costa JL, Garcia FO, Pecorari C. 2000. Effect of No-Tillage on Some  
261 Soil Physical Properties of a Structural Degraded Petrocalcic Paleudol of the Southern  
262 "Pampa" of Argentina. *Soil Tillage Research*, 54, 31-39.
- 263 6. Cavalieri KMV, Silva APD, Tormena CA, Leao TP, Dexter AR, Hakansson I. 2009.  
264 Long-Term Effects of No-Tillage on Dynamic Soil Physical Properties in a Rhodic  
265 Ferrasol in Parana, Brazil. *Soil Tillage Research*, 103, 158-164.
- 266 7. Lawton PJ, Marchant JA. 1980. Direct Shear Testing of Seeds in Bulk. *Journal of*  
267 *Agricultural Engineering Research*, 25, 189-201.
- 268 8. Liu S, Zhang H, Dai Q, Huo H, Xu ZK, Ruan H. 2005. Effects of No-Tillage Plus  
269 Inter-Planting and Remaining Straw on the Field on Cropland Eco-environment and  
270 Wheat Growth. *Ying Yong Sheng Tai Xue Bao*, 16(2), 393-396.

- 271 9. Logsdon SD, Karlen DL. 2004. Bulk Density as a Soil Quality Indicator during  
272 Conversion to No-tillage. *Soil Tillage Research*, 78, 143–149.
- 273 10. Manuwa SI. 2012. Effect of Moisture Content on Rubber, Steel and  
274 Tetrafluoroethylene Materials Sliding on Textured Soils. *Modern Applied Science*, 6,  
275 117-121.
- 276 11. Mehari, A, Schultz B, Depeweg H. 2005. Where Indigenous Water Management  
277 Practices Overcome Failures of Structures: the Wadi Laba Spate Irrigation System in  
278 Eritrea. *Irrigation and Drainage*, 54, 1–14.
- 279 12. Ngapgue F, Madjadoumbaye J, Nouanga P, Amadou T, Tamo TT. 2012. Modeling of  
280 Frictional and Cohesive Resistances of Bafoussam (Cameroon) Soils. *Electronic*  
281 *Journal of Geotechnical Engineering*, 17, 463-472.
- 282 13. Rasouli F, Kiani Pouya A, Afzalinia S. 2012. Effect of Conservation Tillage Methods  
283 on Soil Salinity. *Paper presented at the 8th International Soil Science Congress, Izmir,*  
284 *Turkey*, 15-17 May 2012.
- 285 14. Taser O, Metinoglu F. 2005. Physical and Mechanical Properties of a Clay Soil as  
286 Affected by Tillage Systems for Wheat Growth. *Acta Agriculturae Scandinavica*  
287 *Section B-soil and Plant*, 55, 186-191.
- 288 15. Touchton JT, Rickerl DH, Walker RH, Snipes CE. 1984. Winter Legumes as a  
289 Nitrogen Source for No-tillage Cotton. *Soil Tillage Research*, 4(4), 391-401.