CO₂ emission as a result of the fuel consumption and tillage quality in different tillage conditions

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ABSTRACT

Moldboard plow is the most common primary tillage implement, largest consumer of energy and a significant contributor to CO₂ emission in agriculture. Operational variables in tillage could influence the environment and tillage quality. In the present study a field split-factorial experiment was conducted to examine the influence of soil water content, plowing depth and operating speed in tillage by moldboard plow on clod size, soil inversion, fuel consumption and CO₂ emission as a result of the fuel consumption. Results showed plowing in moist of 15% formed clods significantly smaller than moist of 10% and increased soil inversion. A 33% increase in soil water content increased the fuel consumption and CO₂ emission by 21.21% approximately. Effect of plowing depth on clod size, fuel consumption and CO₂ emission were significant. Plowing at depth of 0.20 m significantly decreased clod size, fuel consumption and CO₂ emission compared with plowing at depth of 0.25 m. The effect of plowing depth on soil inversion was not significant but decreasing plowing depth tends to increase soil inversion. Effect of operating speed on all attributes was significant. Increase operating speed from 3 to 5.5 kmh⁻¹ decreased clod size, fuel consumption and CO₂ emission as a result of the fuel consumption and increased soil inversion significantly.

Keywords: Operational variables, plowing depth, soil moisture content, clod size, soil inversion, moldboard plow.

1. Introduction

Soil tillage, in general, is one of the fundamental agro-technical operations in agriculture because of its influence on soil properties, environment, and crop production (Lal, 1997). Mankind has been tilling agricultural soils for thousands of years to loosen them, to improve their tilth for water use and plant growth and to cover pests (Ahmadi and Mollazade, 2009). Tillage is a process of creating a desired final soil condition for seeds from some undesirable initial soil condition through manipulation of soil with the purpose of increasing crop yield (Al-Suhaibani and Ghaly, 2010). The moldboard plow is one of the oldest of all agricultural implement and is generally considered to be the most important tillage implement (kepner et al., 2005). The moldboard plow is the most common primary tillage implement and the largest consumer of energy in agriculture (Filipovic et al., 2006).

In order to efficiently handle the demand in agricultural food production, soil physical properties must be managed adequately. The influence of tillage implements on soil physical properties is significant. Soil physical properties change not only because of constructional properties of soil tillage implements, but also because of their operational variables, such as operating speed, plowing depth and soil water content. The soil physical properties’ changes...
resultant from soil tillage treatments and operational variables could influence the yield level of grown crops (Boydas and Turgut, 2007).

Soil fragmentation is a primary aim in tillage in order to create a favorable soil environment for crop growth. Soil fragmentation is defined as the process of breakdown and crumbling of soil aggregates (Abbaspour-Gilandeh et al., 2009). Soil aggregation plays an important role in the maintenance of soil productivity and quality. Well aggregated soils physically protect soil organic matter and affects root density and elongation, soil erosion, oxygen diffusion, soil water retention and dynamics, nutrient adsorption and microbial community structure (Six et al., 2004). The size of aggregates and aggregation state are affected by tillage conditions and operational variables (Boydas and Turgut, 2007). Karlen et al. (1994) suggested that aggregate size distribution is good indicator for evaluating soil quality in tillage experiments. Many researchers have studied the effect of operational variables on the aggregate size distribution and seed-bed condition (Loghavi and Behnam, 1999; Solhjou et al., 2002; Hemmat et al., 2007). Ahmadi and Mollazade (2009) indicated that soil aggregation changes due to tillage are related to the soil moisture content, soil type and plowing depth. Several researchers (Taniguchi et al., 1999; Kabiri and Zarean, 2002) reported that an increase in tillage operating speed resulted in more soil pulverization. Several researchers have been investigated the effects of soil water content at the time of tillage on the aggregate size distribution resulting from a tillage operation (Wagner et al., 1992). Hemmat et al. (2007) reported that when soil is worked at water contents near the lower plastic limit, it tends to be most friable, large clods fragment easily into smaller aggregates, and structural damage can be accelerated. Several works (Adam and Erbach, 1992; Ahmadi and Mollazade, 2009) related to tillage-induced soil aggregate size distribution showed that large aggregates are formed at both high and low water contents. Solhjou et al. (2002) concluded that soil water content at the time of tillage significantly affected the resulting aggregate size distribution; maximum aggregate breakdown occurred when the soil was tilled at water contents near the optimum water content for compaction as determined by a standard Proctor test.

Soil fragmentation/aggregation may be determined by measurements such as the increase in surface area or decrease in Mean Weight Diameter (MWD). The results may be expressed in terms of the actual size distribution of the clods, a mean-mass diameter, or a pulverization modulus (Abbaspour-Gilandeh et al., 2009).

Tillage plays an important role in controlling weeds and managing crop residues. The moldboard plow has the ability to turn over and cover sods, crop residues, and weeds. Historically, one of the main functions of moldboard plough has been to turn over the soil. The plough buries residues and weeds to create clean seedbed suitable for germination and growth of the plant, and functions as one of the effective methods of weed control (Shoji, 2001). Soil inversion is indicator for expressing this ability (RNAM, 1995). Soil inversion is changed by the operational variables in tillage by moldboard plow. Several works investigated the effect of operational variables such as plowing depth and operating speed on soil inversion (Loghavi and Behnam, 1999; Kabiri and Zarean, 2002). Kabiri and Zarean (2002) reported that increasing the plowing depth and/or the forward speed improved the quality and quantity of soil inversion.

Global warming resulting from greenhouse gas emissions (especially carbon dioxide) of agricultural origin has been deemed one of the most important current environmental impact issues. In case of arable land crop production, release and uptake of carbon dioxide (CO$_2$) emissions is largely the result of burning fossil fuels. Therefore, in designing environment-friendly agricultural systems, fuel-saving protocols can be a key tool in reducing CO$_2$
emissions in fuel-dependent cropping systems (Koga et al., 2003). The soil tillage is one of the operations that require the most direct energy in arable production. (Filipovic et al., 2006). Robertson et al. (2000) reported that in arable land crop production of CO₂ emissions is largely the result of burning fossil fuels. Lal (2004) reported that tillage is among the most important sources of CO₂ emission. Koga et al. (2003) stated tillage-related operations including soil preparation and plowing had a great influence on total CO₂ emissions, accounting for 23–44% of total CO₂ emissions. Filipovic et al. (2006) investigated the influence of different tillage systems on fuel consumption and CO₂ emission. Their results showed that the conventional tillage system was the basic source of the large quantities of CO₂ emissions and the reduced tillage system assured the reduction of CO₂ emission.

It was hypothesized that tillage in good operational variables can improve tillage quality and minimize agricultural impact on global CO₂ increase. The objective of the present study was to evaluate the effects of operating speed, plowing depth and soil water content on aggregate size distribution measured as mean weight diameter, soil inversion, and fuel consumption also identifying the CO₂ emission as a result of the fuel consumption.

2. Materials and Method

Field experiments were conducted at the farm of University of Tehran in Karaj city with loamy soil texture (consisted of 26% clay, 35% silt and 39% sand) and 300 mm average rainfall. The experiments were conducted during the September and October of 2009. The experimental site was cropped with wheat (*Triticum aestivum* L.) in previous year. A mounted moldboard plow (3 bottoms with a 0.35 m working width) was used for all the tests. Moldboard plow was pulled by a John Deere 3140 Model tractor with 100 hp power.

The statistical design used in this experiment was a randomized block design, in a split-factorial scheme. Independent variables were soil water content, plowing depth and operating speed, and dependent variables were clod mean weight diameter, soil inversion, fuel consumption and CO₂ emission as a result of the fuel consumption. Different levels of soil moisture content were main plots, and different factorial levels of depth and speed were subplots. All factors had two levels. Soil moisture contents of 10% and 15% dry weight basis were different levels of main factor. The two levels of plowing depth were 0.20 and 0.25 m and levels of operating speed were 3 and 5.5 kmh⁻¹. The selected working depths and speeds were commonly used by farmers and represent actual working conditions. The experiment was replicated three times for a total of 24 experimental units. Each subplot was 33×3.75 m.

The clod mean weight diameter was determined as an index of soil pulverization, using dry sieving. After plowing, rectangular soil samples were taken from each subplot. A 0.5×0.5 m frame was used to surround the soil sample; then the soil was removed to the depth of work by hand, to prevent soil clod break-up. The moist soil samples were allowed to air dry prior to sieving. A set of sieves of 125, 75, 50, 40, 20 and 10 mm mesh openings was used. The soil sample was passed through the set of sieves, and the cumulative amount of soil retained on each sieve was weighed. The soil that passed through the sieve with the smallest aperture was also weighed. The clod mean weight diameter was calculated by using the formula below (Hemmat et al., 2007):

\[ MWD = \sum X_i \times W_i \]  

(1)
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Where; MWD is the clod mean weight diameter in mm; \( X_i \) is average clod diameter in a particular sieve in mm; and \( W_i \) the weight of clods in the size range \( i \), as a proportion of total dry weight of sample analyzed.

Soil inversion is quantitatively expressed as of numbers or amount of weeds or stubbles of last crop left on soil surface after operation to that before it. In this study prior and after to tillage operations two samples from each subplot were measured. A 0.5×0.5 m frame was used to convenient and surround weeds and stubbles. The weed and stubble samples were dried in an oven at a constant temperature of 105\(^\circ\)C for 24 hours. Then, the oven dried samples were weighed. The soil inversion for each plot was calculated using the following equation (Loghavi and Behnam, 1999):

\[
F = \frac{W_p - W_e}{W_e} \times 100
\]

Where; \( F \) is indicator for soil inversion in percent; \( W_p \) is weight of weed or crop stubble before operation per unit area in gr; and \( W_e \) is weight of weed or crop exposed on the surface after operation per unit area in gr.

Fuel consumption rate in operation was measured by starting working the subplot with full tank capacity. After finishing the subplot, the fuel tank was refilled with a graduated cylinder with an accuracy of 1.00 mL. Amount of refueling after the test is the fuel consumption for the test (Mehta et al., 2005). The calculation of the CO\textsubscript{2} emission was based on the tractor fuel consumption and the datum that the combustion of 1.00 L diesel oil results in the emission of 2.75 kg CO\textsubscript{2} (Filipovic et al., 2006).

The data were initially tested for normality; standard deviations were calculated and then treatment effects were analyzed by analysis of variance (ANOVA) procedures using the SAS Statistical Software Package (SAS Institute, 2009). When the F-test indicated statistical significance at the P=0.05 probability level, treatment means were separated by least significant difference (LSD\textsubscript{0.05}) test.

3. Results and Discussion

Table 1 shows the mean values for the four attributes used to evaluate the performance of the moldboard plow under study and their corresponding mean comparison test results.

The results of this study are discussed under the following headings:

3.1. Clod mean weight diameter:
As table 1 shows influence of soil moisture on clod mean weight diameter is significant statistically. Plowing in moist soil condition (15% dry weight basis) formed clods significantly smaller than under dry soil condition (10% dry weight basis) (Table 1). The trend in clod mean weight diameter revealed that a 33% decrease in soil moisture increased the clod mean weight diameter by 46.60% approximately. Similarly Hemmat et al. (2007) and arvidsson et al. (2004) reported that the smallest proportion of coarse clods occurred under moist conditions.

Table 1 shows influence of plowing depth on clod MWD is significant. This means, plowing in depth of 0.20 m formed significantly smaller clod MWD when compared with the plowing
in 0.25 m depth. Similar results were observed by other researches (Hemmat et al., 2007; Ahmadi and mollazade, 2009).

**Table 1:** Analysis of the effect of the factors over the range of test conditions

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Clod MWD (mm)</th>
<th>Soil inversion (%)</th>
<th>Fuel consumption (lha$^{-1}$)</th>
<th>CO$_2$ emission (kg ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil moisture (M)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M$_1$=10%</td>
<td>28.37$^a$</td>
<td>90.83$^a$</td>
<td>26.45$^a$</td>
<td>72.74$^a$</td>
</tr>
<tr>
<td>M$_2$=15%</td>
<td>15.15$^b$</td>
<td>95.54$^b$</td>
<td>20.84$^b$</td>
<td>57.31$^b$</td>
</tr>
<tr>
<td>Plowing depth (D)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D$_1$=0.20 m</td>
<td>16.90$^a$</td>
<td>93.71$^a$</td>
<td>23.50$^a$</td>
<td>64.63$^a$</td>
</tr>
<tr>
<td>D$_2$=0.25 m</td>
<td>26.63$^b$</td>
<td>92.66$^b$</td>
<td>28.05$^b$</td>
<td>77.14$^b$</td>
</tr>
<tr>
<td>Operating speed (S)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S$_1$=3 kmh$^{-1}$</td>
<td>18.54$^a$</td>
<td>91.65$^a$</td>
<td>27.38$^a$</td>
<td>75.30$^a$</td>
</tr>
<tr>
<td>S$_2$=5.5 kmh$^{-1}$</td>
<td>24.99$^b$</td>
<td>94.72$^b$</td>
<td>21.44$^b$</td>
<td>58.96$^b$</td>
</tr>
</tbody>
</table>

(1) Means for the same attribute, followed by the same letter, do not statistically differ among themselves at the 5% probability level.

As Table 1 shows, the influence of tractor forward speed in tillage operation is significant on clod MWD. Plowing in 5.5 kmh$^{-1}$ speed formed clods significantly smaller than 3 kmh$^{-1}$ speed. Results showed that a 45% increase tractor travel speed decreased the clod MWD by 25.81% approximately (Table 1). By increasing plowing speed, pulverization was increased and that caused small clod formation. This is in accordance with Kabiri and Zarean (2002) who found that there was inverse relationship between clod MWD and plowing speed.

Results of analysis of variance for clod MWD attribute showed that interaction between soil moisture and plowing depth (MxD) were significant statistically. Therefore treatment means were separated by least significant difference test and result showed in figure 1.

**Figure 1:** Clod MWD in different levels of soil moisture (M) and plowing depth (D) (Histogram followed by same letter are not significantly different at probability P<0.05 according to least-significant difference)
As Figure 1 shows the smallest and largest clods were formed in treatments of (15% moisture × 0.20 m plowing depth) and (10% moisture × 0.25 m plowing depth) with mean weight diameters of 13.04 mm and 36.00 mm respectively. Difference treatment with largest clod size was significant with other treatments (Figure 1). Figure 1 show in soil moisture of 10%, plowing formed clods significantly smaller under plowing 0.20 m deep than under plowing 0.25 m deep. Similarly in soil moisture of 15% increasing plowing depth tends to increase clod MWD but this increasing was not significant statistically (Figure 1).

3.2. Soil inversion

The results for soil inversion in Table 1 show that there were significant variations between soil moisture of 10% and soil moisture of 15%. The test demonstrates that the soil inversion means, in soil moisture of 15%, is 4.71% more than moisture of 10% (Table 1). This could be explained by the fact that increasing pulverization as a result of the moist condition increased soil covering.

The analysis of variance for soil inversion in Table 1 showed that the main effect of plowing depth was not significant statistically. Although this effect is insignificant but as table 1 showed, decreasing plowing depth tends to increase soil inversion by average 1% approximately. Although the results of present study explained that the effect of plowing depth on soil inversion was not significant, Kabiri and Zarean (2002) reported that the effect of plowing depth on soil inversion was significant at 1% probability level and increase in plowing depth increased the soil inversion.

The result of analysis of variance in Table 1 shows that the effect of operating speed on soil inversion was significant. Results shows that a greater percentage of soil inversion was produced when soil was tilled at 5.5 kmh⁻¹ compared with 3 kmh⁻¹ plowing speed. Similar results were observed by other researchers (Kabiri and Zarean, 2002) that with increasing plowing speed, soil inversion increased. Kabiri and Zarean (2002) concluded that soil inversion in depth of 0.25 m and plowing speeds of 2.86, 4.40 and 5.58 kmh⁻¹ were 85.73, 86.68 and 90.28% respectively.

The soil water content × plowing depth interactions (M×D) and soil water content × operating speed interactions (M×S) were significant for soil inversion. Compare means of soil inversion in different levels of soil moisture (M) and plowing depth (D) were showed in Figure 2 and in different levels of soil moisture (M) and plowing speed (S) were showed in Figure 3.

As Figure 2 shows in plowing depth of 0.20 m, plowing at low soil moisture content (i.e., 10% dry weight basis) reduced significantly the soil inversion when compared with plowing at moist soil water content (i.e., 15% dry weight basis). Figure 2 shows for the plowing depth of 0.25 m although soil inversion increased as soil water content increased but this effect was not significant. Result showed that maximum amount of soil inversion was occurred in treatment of 15% of soil water content × 0.20 m of depth × 3 kmh⁻¹ of speed with 96.33% approximately while average of soil inversion in experiment was about 93.18%.
Figure 2: Soil inversion in different levels of soil moisture (M) and plowing depth (D) (Histogram followed by same letter are not significantly different at probability P<0.05 according to least-significant difference)

Figure 3: Soil inversion in different levels of soil moisture (M) and plowing speed (S) (Histogram followed by same letter are not significantly different at probability P<0.05 according to least-significant difference)

Figure 3 depicted compare means of soil inversion in different levels of soil moisture (M) and operating speed (S). In soil water content of 10%, increasing plowing speed increased soil inversion significantly (Figure 3). Although in soil water content of 15%, difference between speed of 3 km h⁻¹ and speed of 5.5 km h⁻¹ was insignificant but the trend in soil inversion showed that increase in plowing speed increased the soil inversion (Figure 3). Figure 3 shows in plowing speed of 3 km h⁻¹ the effect of soil water content on soil inversion was significant and increase soil moisture content increased the soil inversion. Similarly result was observed for speed of 5.5 km h⁻¹ but this difference was not significant statistically (Figure 3). Figure 3 shows that maximum and minimum amount of soil inversion were occurred in treatment of (soil water content of 15% × plowing speed of 5.5 km h⁻¹) and (soil water content of 10% × plowing speed of 3 km h⁻¹) respectively.
3.3. Fuel consumption and CO\textsubscript{2} emission

Table 1 shows the effect of soil water content on fuel consumption therefore on CO\textsubscript{2} emission was significant. Fuel consumption and CO\textsubscript{2} emission in soil water content of 10% treatment was statistically different from that of soil water content of 15% treatment (Table 1). Plowing at low soil water content (i.e., 10% dry weight basis) significantly increased the fuel consumption and CO\textsubscript{2} emission by 21.21% when compared with plowing at moist soil water content (i.e., 15% dry weight basis) (Table 1). These observations are in agreement with those made by Cullum et al. (1989) and Abbaspour-Gilandeh et al. (2006). They observed that there was inverse relationship between fuel consumption and soil water content.

Table 1 shows the effect of plowing depth on fuel consumption and CO\textsubscript{2} emission is significant. Fuel consumption and CO\textsubscript{2} emission increased with increase the working depth during plowing (Table 1). The average fuel consumption is 25 Lha\textsuperscript{-1} approximately which is close to results reported from other researchers (Filipovic et al., 2006; Fathollahzadeh et al., 2009). The results showed that with increasing depth from 0.20 to 0.25 m fuel consumption increased by 16.22% approximately. This result was consistent with finding reported by other authors (Soltani-Ghalehjoghi and Loghavi, 2007; Fathollahzadeh et al. 2009). Fathollahzadeh et al. (2009) noted that a John Deer 3140 tractor with three-share disc plough attached, operating at depths of 0.15, 0.23 and 0.30 m, usually consumes 19.667, 24.715 and 28.646 Lh\textsuperscript{-1}, respectively.

The effect of plowing speed on fuel consumption was significant (Table 1). Table 1 shows fuel consumption and CO\textsubscript{2} emission increased as the operating speed of tractor increased. The results from this experiment are in agreement with that of Kheiralla et al. (2004) that stated there was inverse relationship between fuel consumption and plowing speed. Result showed that average of fuel consumption for speeds 3 and 5.5 kmh\textsuperscript{-1} were 27.38 and 21.44 Lha\textsuperscript{-1} respectively. This means that a 45% increase in plowing speed decreased the CO\textsubscript{2} emission as a result of the fuel consumption by 21.69% approximately. Koga et al. (2003) and Filipovic et al. (2006) reported that the CO\textsubscript{2} emission rates could be reduced by managing tillage systems, as a consequence of fuel savings.

Analysis of variance showed that there were no significant interactions between treatments for fuel consumption and CO\textsubscript{2} emission; therefore treatment means were not separated by least significant difference (LSD\textsubscript{0.05}) test.

4. Conclusion

1. Soil water content has significant influence on clod size, soil inversion, fuel consumption and CO\textsubscript{2} emission. Increase in soil water content decreased the clods size, fuel consumption and CO\textsubscript{2} emission and increased the soil inversion significantly.

2. Effect of plowing depth on clods size, fuel consumption and CO\textsubscript{2} emission as a result of the fuel consumption was significant. Decrease in plowing depth significantly decreased clods size, fuel consumption and CO\textsubscript{2} emission. The effect of plowing depth on soil inversion was not significant. However, the soil inversion tends to increase with decreasing plowing depth.
3. Effect of operating speed on clod size, fuel consumption, CO₂ emission and soil inversion was significant. Soil inversion increased as the operating speed increased but there were inverse relationship between operating speed with clods size, fuel consumption and CO₂ emission.

4. Work in conditions with appropriate operational variables can improve tillage quality and decrease environmental impact issues in tillage.

5. References


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27. Taniguchi, T., Makanga, J.T., Ohtoma, K., Kishimoto, T. (1999), Draft and soil manipulation by a moldboard plow under different forward speed and body attachments, Transactions of the ASAE, 42, pp 1517-1521.