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Performance Evaluation of Compound Tillage Machines with Different Configurations, in terms of Soil Fragmentation Index and Soil Clod Size

Karar I. Taha and Aqeel J. Nassir*
Department of Agriculture Machines and Equipment, College of Agriculture, University of Basrah, Iraq

*Corresponding author-mail: aqeel.nassir@uobasrah.edu.iq

1. Abstract

The field experiment was carried out at Karma Ali, the Agricultural Research Station of the College of Agriculture, University of Basrah, located between latitude 30 ° 33 ‘20 " N and longitude 47 ° 44’54 " E. The objective was to evaluate the performance of different configurations of compound tillage machines. Six configurations were tested: a chisel plow with sickle fins on the front and rear shanks combined with a rigid harrow (CF2H), a chisel plow with sickle fins only on the rear shanks and a rigid harrow (CFH), a basic chisel plow with a rigid harrow (CH), a chisel plow with sickle fins on both front and rear shanks (CF2), a standard chisel plow without any fins combined with a rigid harrow (CF) and a conventional chisel plow (C). These were tested at two forward speeds, 2. 35 km/h and 3. 86 km h^{-1}, using a randomized complete block design (RCBD) with three replications. Data were analyzed with the least significant difference (LSD) test at the significance level of 0. 05. The results showed significant differences among tillage configurations and speeds. The compound configuration CF2H (chisel plow with sickle fins on the front and rear shanks plus rigid harrow) consistently recorded the lowest soil fragmentation index compared to all other treatments. Specifically, CF2H reduced fragmentation by 7. 07–73.54. 54% relative to CFH, CH, CF, and C. Conversely, the conventional chisel plow (C) exhibited the highest fragmentation index (69. 11 mm at 2.35 km h^{-1}). The interaction between tillage type and speed was highly significant, as compound tillage machines combined with higher speeds enhanced soil crushing efficiency more than conventional plows. Moreover, CF2H enhanced the formation of soil clods smaller than 5 cm (N>5), but the standard chisel plow proved to be less efficient. These data validate that integrated tillage systems, when paired with optimal forward speeds, significantly enhance soil preparation relative to traditional approaches.
Keywords: Combined plow, Soil fragmentation index, Forward speed, Clod size

I. INTRODUCTION

Tillage is one of the important agricultural operations carried out in the field to improve the various physical, chemical, and biological properties of the soil (Tagar et al., 2020; Nassir et al., 2023; Muhsin et al., 2025). Tillage practices lead to the compacted and cohesive soil layers being broken down and fragmented to facilitate soil aeration and water drainage, which helps plant root development and increases the production of plants (Nassir et al., 2024). Despite the many advantages of the tillage operation, tillage using conventional methods requires a significant amount of energy, accounting for approximately 60% of the total energy (Jacobs and Harrol,1983). Furthermore, preparing the soil using conventional methods, particularly in heavy clay soils, requires the plowing machines to pass more than once in the field, which causes soil compaction, negatively affects the soil properties. To solve this problem, compound plowing machines can be used, which can shorten the process of passing through the field to one time, reducing the energy consumed and reducing soil compaction. Soil pulverization index is one of the most important factors that can be studied to evaluate tillage equipment, as this index improves under the influence of the use of compound tillage equipment compared to

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traditional tillage equipment. This index is affected by several operational factors, including operating speed, tillage depth, soil moisture, and soil texture (Nassir et al., 2024). In a study of pulverization compound tillage equipment with traditional methods of soil preparation, Usaborisut and Prasertkan (2019) found that the compound tillage machine consists of a chisel plow and rotary harrow, reduced the soil pulverization index by 21.30% compared to traditional methods in soil preparation for cultivation. Nasser et al. (2022) reported that the use of a cultivator consisting of a chisel plow + a disc harrow + a roller led to a reduction in the fragmentation index values by 42.28%% compared to traditional methods. Karim and Jassim (2024) reported that adding wings to the shanks of plow reduced the size of soil clods by 30% compared to a traditional plow without wings. Soil fragmentation using compound plowing equipment can reduce the energy consumed in the field by 44 to 50% (Hamid, 2024). Choudhary et al., 2021) found that when using a compound tillage machine consisting of a chisel plow plus a disc harrow. This led to the compound tillage machine reducing the soil fragmentation index from 31.77 to 26.57 mm compared to traditional methods when preparing sandy loam soil. Nasser et al. (2022) also reported that the use of a cultivator consisting of a chisel plow plus a disc harrow plus a roller led to a reduction in the fragmentation index values by 23 and 85% compared to traditional methods . The tillage appearance is an important indicator of its effectiveness in breaking soil clods into smaller pieces (Al-Jaradi et al., 2022): Jassim and Saadoun (2016) reported that the number of soil clods less than 5 cm m^{-2} using the chisel plow, followed by using the spring harrow teeth, led to an increase number of clods less than 5 clods m^{-2} by 18% comberd to conventional methods. Rashid (2024) reported that using the chisel plow and the grid leveling machine increased the percentage of soil clods smaller than 5 clods m^{-2} to 22.71% compared to traditional soil preparation methods. Despite the interest in compound plowing machines, the emphasis is on using this equipment in conservation tillage (Kumar et al., 2021). Tillage machines that do not turn the soil are limited, so a machine was manufactured. The compound tillage machine consists of a shank with curved fins to enhance soil fragmentation and loosening. Additionally, the compound machine is equipped with a rigid harrow behind the main plow. This tillage machine does not overturn the soil, thereby improving soil properties and reducing soil degradation and erosion that can occur with intensive tillage methods such as plowing with moldboard plow, disc plows, or rotary tillers (Trendafilov et al., 2024). It was designed to address issues related to soil degradation and soil structure. Its performance was evaluated based on its ability to fragment and break up soil, using criteria that included the fragmentation index and the size of soil clods less than five centimeters per square meter. The combined tillage machine was evaluated with six different configurations and two forward speeds.

II. MATERIAL AND METHODS

Experiment Location

The study was carried out in one of the fields of the Agricultural Research Station affiliated with the College of Agriculture, University of Basrah, at the Karma Ali site (Fig. 1), located between latitude 30 ° 33 ‘20 " N and longitude 47 ° 44’54 " E. Initial physical and mechanical properties. Soil samples were taken from the field used in the study to measure the initial soil properties, with three replicates at depths of 0-10,10-20 and 20-30 cm, as shown in Table 1.

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Figure 1. Located of experiment fields

Table 1. Initial soil properties of the experiment field

		Soil depth (cm)		
Soil Properties	**Units**	**0-10**	**10-20**	**20-30**
Sand	g kg^{-1}	65.02	60.52	50.68
Silt		349.35	344.63	334.61
Clay		585.63	594.85	614.71
Soil texture		Clay	Clay	Clay
Bulk Density	Mg m^{-3}	1.28	1.35	1.47
Real Density		2.58	2.61	2.66
Porosity	%	50.39	48.28	44.74
Moisture Content	%	14.48	18.33	20.24
Soil Penetration Resistance	kN m^{-2}	1879	2792	3351
Cohesion	kN m^{-2}	9.59	14.02	18.03
Internal Angle of Friction		˚12	˚14	˚16
Adhesion	kN m^{-2}		0.28	

The compound tillage machine

The compound tillage machine (Fig.2) was manufactured in the workshops of the Department of Agricultural Machinery and Equipment at the College of Agriculture of the University of Basrah. The compound tillage machine consists of a chisel plow and a rigid harrow. The chisel plow consists of a rectangular frame made of high-carbon steel. The plow shanks are straight blades also made of high-carbon steel. These shanks are mounted on the plow frame in two rows: a front row containing two shanks and a rear row containing three shanks. The blades in the front and rear rows are placed alternately. Each shank of the chisel plow is fitted with a curved sickle-shaped appendage. These fins are placed on both sides of the shank to increase the loosening and fragmentation. These fins are fixed to the shanks by screws. These fins can be removed or kept according to the required structure in the plowing and soil preparation process.

The chisel plow frame is combined with a ridge harrow frame, which consists of a rectangular structure made of angle iron. The ridge shanks are arranged in two rows in the frame. The front row contains four ridge shanks and the rear row contains five ridge shanks. The shanks in the two rows alternate with the front row in order to increase the loosening and fragmentation of the soil and not leave any soil unplowed by the chisel shanks. The compound tillage machine is used with six different configurations, which are the following:

- A compound tillage machine consisting of a chisel plow with sickle fins in the front and rear shanks and a rigid harrow (CF2H).
- A compound tillage machine consisting of a chisel plow with sickle fins on only the rear shanks and a rigid harrow (CFH).
- A compound tillage machine consisting of a chisel plow and a rigid harrow (CH).
- A chisel plow with sickle fins on the front and rear shanks (CF2).
- A compound tillage machine consisting of a chisel plow (without adding fins) and a rigid harrow (CF).
- Conventional chisel plow (C).

The compound tillage configurations are used at two forward speeds.

- 2.35 km h^{-1}
- 3.86 km h^{-1}

Figure 2. Different photos of a combined tillage machine

Soil fragmentation index

After conducting experiments using a compound tiller with six configurations (C2FH, CFH, CH, C2F, CF and C) and two tillage speeds (1.76 and 3.85 km h^{-1}). The plowed soil samples were collected, each measuring 50 cm in length and with a width equal to the tiller working width (196 cm), with three replicates for each treatment. These samples were transported to the laboratory and allowed to air dry. The dry soil samples were then sifted using an electric sieve, which contains a set of sieves with different diameters (100, 75, 50, 26.5, 16, and 2 mm). After the sieving process, the soil clods remaining on top of each sieve were weighed, and the total weight of the sample was calculated by adding the weights of the soil collected on each sieve. Then the percentage of each weight on each sieve was calculated using equation 1 according to the method mentioned in Hillel (1980).

$$SPI = \frac{\sum_{i=1}^{n} Qi * xi}{Q_{total}} \qquad (1)$$

Where: *SPI*: Pulverization index (mm). *Qi*: Percentage of soil mass remaining on each sieve after sieving (mm). Q_{Total}: Total soil sample mass (kg). *X*i: Average diameter of two consecutive sieves (mm). (For example, if the diameter of the previous sieve is 100 mm and the next sieve is 75 mm, then the average = (100 + 75) / 2 = 87.5 mm).

Determination of soil clod size (N>5)

The soil clod size was estimated for less than 5 cm using a frame with a specified area (1 m²) and the sieve analysis method. A sieve has a mesh of 5 cm. Soil samples were taken randomly, avoiding the field edges and tractor paths. Samples were collected from inside the frame and sifted. The remaining weight of clods on the

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sieve indicates the number of clods larger than 5 cm, while the clods that fall through the sieve represent the number of clods smaller than 5 cm per square meter. Three replicates were taken for each treatment with the compound tillage machine.

Statistical analysis

Six different plow types (C2FH, CFH, CH, C2F, CF, and C) and two tillage speeds (1.76 and 3.85 km h^{-1}) were used in the field experiment. Tillage treatments were placed in the main plots and tillage speed (forward speed) in the secondary plots, and treatments were distributed randomly in the plots. Overall 36 plots, arranged factorial (6 x 2) design in a randomized complete block design (RCBD) with three replications. Each plot has an area of 39.20 m2 [20 m for length and 1.96 m for plow width]. Data for all experiments were analyzed statistically using the statistical program Genstat 2012, and the means of treatments were compared by the least significant difference (LSD) test at the probability level of 0.05 according to Al-Rawi and Khalaf Allah (1980).

III. RESULTS AND DISCUSSION

Soil fragmentation index

The results of the statistical analysis showed a highly significant effect of the tillage treatments using a combined tillage machine on the soil fragmentation index. Figure 2. indicated that the soil fragmentation index decreased for the combined combinations of tillage machines that included secondary soil preparation equipment (chisel plow with sickle fins on both the front and rear shanks and a rigid harrow (CF2H)). The CF2H treatment recorded the lowest soil fragmentation index compared to CFH, CH, C2F, CF, and C by 7.07%, 23.61%, 9.86%, 13.32% and 73.54%, respectively. CFH, CH, C2F, and CF had lower soil fragmentation indices than C (control treatment) by 71.53%, 65.36%, 70.65% and 69.47%, respectively. This difference may be attributed to the fact that the combined plow, which includes a chisel plow equipped with sickle fins and a rigid harrow, can loosen the soil and break it into smaller pieces by trapping large blocks between the sickle fins, which break up the soil blocks. The rigid harrow then passes over these clumps, breaking them into small pieces with an average diameter of 26.15 mm. In contrast, the use of a conventional chisel plow to treat the soil results in the soil splitting and breaking up, leaving large clumps on the surface. This leads to an increase in the fragmentation index, which reached 98.83 mm. This outcome is consistent with the findings of Nassir et al. (2022), who reported that the soil fragmentation index (PI) using a combined tillage machine (chisel plow + disc harrow + roller) decreased by 11.38% compared to using a conventional chisel plow.

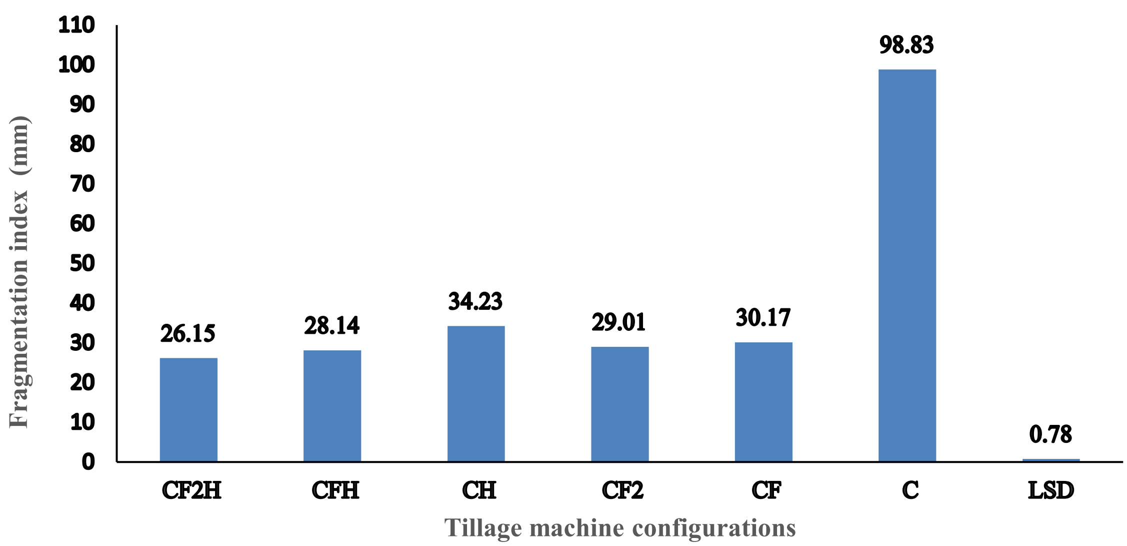

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Figure 2. Effect of tillage machine configurations on fragmentation index

The results of the statistical analysis showed a highly significant effect of the forward speed on the soil fragmentation index. The crushing index decreased with increasing forward speed (Fig. 3). Increasing forward speed increases the acceleration of soil masses, leading to their self-disintegration as a result of increased collisions between them. This contributes to the fragmentation of most soil blocks into smaller masses. When the forward speed increased from 2.35 to 3.86 km h^{-1}, the fragmentation index decreased from 34.47 to 39.23 mm. This result is consistent with Upadhyay and Raheman (2020), they found that when the forward speed increased from 3.46 to 6.84 km h^{-1}, the fragmentation index decreased from 30.25 to 24.86 mm and attributed the reason to the increase in acceleration and collision of the soil masses, which increased the chance of self-fragmentation of the masses.

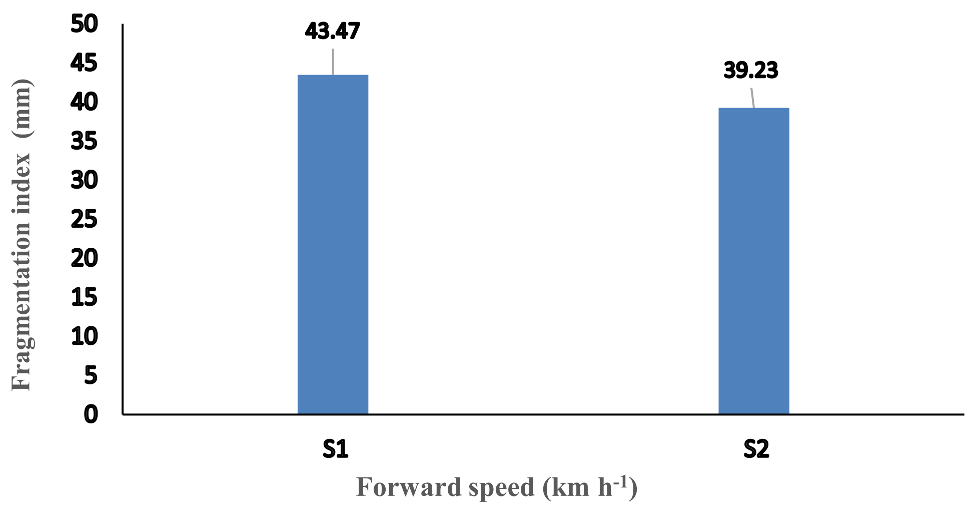

Figure 3. Effect of forward speed on fragmentation index

The results of the statistical analysis showed a highly significant interaction between the tillage parameters using a combined plow and forward speed on the soil crushing index. Figure 4 shows the significant superiority of the tillage parameters that include secondary tillage equipment and a high forward speed in increasing soil fragmentation (lower fragmentation index) compared to a conventional chisel plow at a slow forward speed. The tillage treatments using compound tillage machines C2FH, CFH, CH, C2F and CF compound tillage machines achieved the lowest soil disintegration index, reaching 23.91, 27.63, 35.8, 27.44, and 27.93 mm, at a forward speed of 3.86 km h^{-1}, respectively, while the conventional chisel plow recorded the highest soil fragmentation index values, reaching 69.11 and 55.56 mm, respectively, at a forward speed of 2.35 km h^{-1}. The reason for the increased fragmentation of tillage treatments using compound tillage machines is due to the presence of secondary soil preparation equipment (rigid harrows and sickle fins) within the components of the machine, combined with tillage treatments. In addition, increased forward speed leads to increased acceleration of the soil masses, which increases the collision of the soil masses with each other, which causes self-fragmentation of the soil masses, which in turn leads to increased soil fragmentation (decrease in the soil fragmentation index). This result is consistent with the findings of Argyrokastritis and Natsis (2011).

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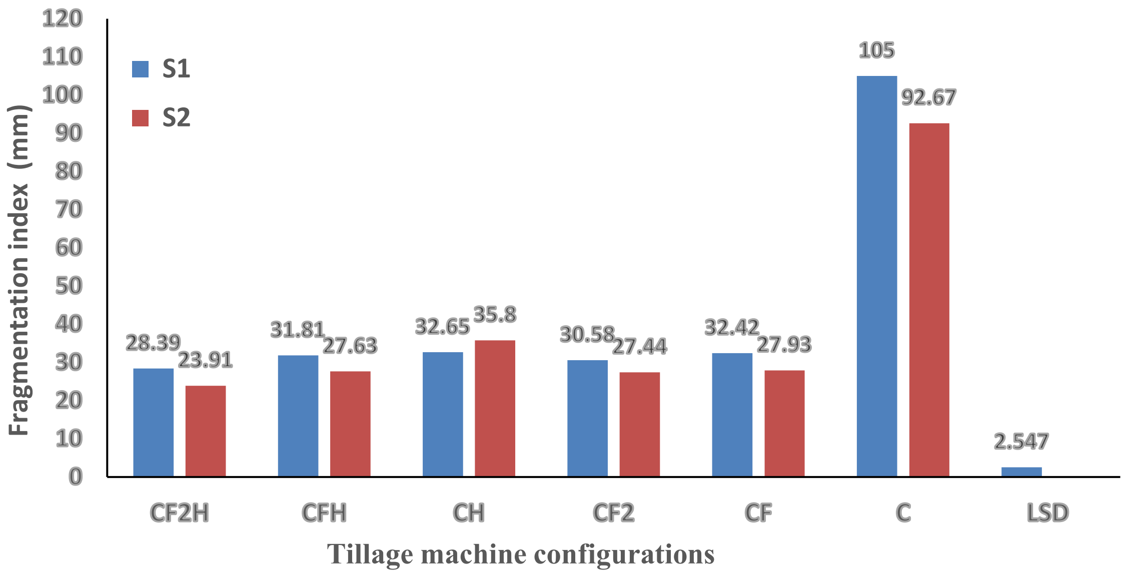

Figure 4. Effect of interaction between tillage machine configurations and forward speed on fragmentation index

Clods size less than 5 cm (N>5)

The results of the statistical analysis showed a highly significant effect of the tillage treatments using a combined tillage machine on the number of soil clods less than 5 cm (N>5). Figure 5. showed that N>5 increased for the combined combinations of tillage machines that included secondary soil preparation equipment (chisel plow with sickle fins in the front and rear shanks and a rigid harrow (CF2H)). CF2H treatment recorded the lowest soil fragmentation index compared to CFH, CH, C2F, CF, and C by 9.20, 23.63, 22.70, 34.13, and 134.18%, respectively. CFH, CH, C2F and CF had higher (N>5) than C (control treatment) by 114.44, 89.42, 90.84, and 74.59%, respectively. This difference can be attributed to the fact that the combined plow, which includes a chisel plow equipped with sickle fins and a rigid harrow, can loosen the soil and break it into smaller pieces by breaking large blocks with the sickle fins, which break the soil blocks. The rigid harrow then passes over these clumps, breaking them into small pieces, thus increasing the number of soil clods less than 5 cm m^{-2}. This result is consistent with the findings of Abbaspour-Gilandeh (2009).

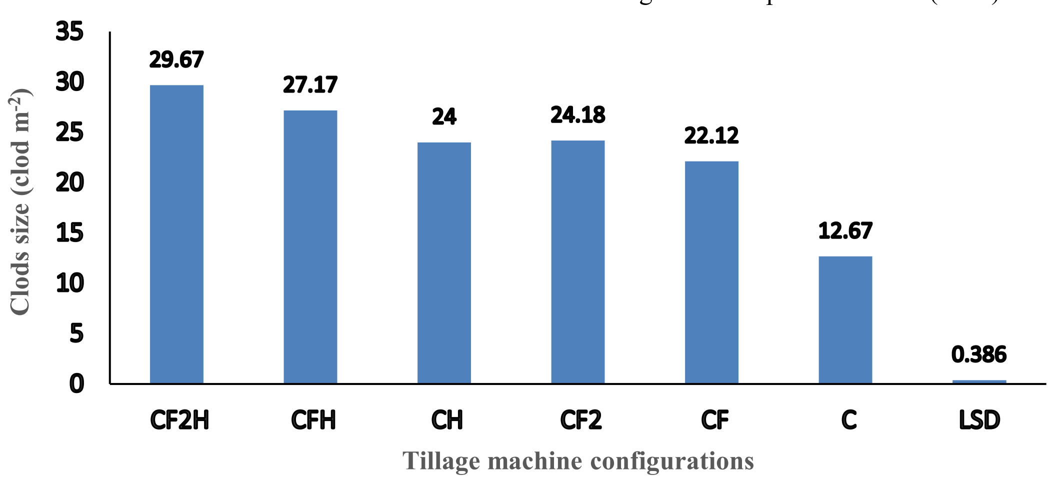

Figure 5. Effect of tillage machine configurations on clods size of soil

The results of the statistical analysis showed a highly significant effect of the forward speed on the soil crushing index. The number of soil clods less than 5 cm (N>5) increased with increasing forward speed (Figure 6). Increasing forward speed increases the acceleration of soil masses, leading to their self-disintegration as a result of increased collisions between them. This contributes to the fragmentation of most soil blocks into smaller masses. When forward speed increased from 2.35 to 3.86 km h^{-1}, the number of soil clods less than 5 cm (N>5) increased from 21.72 to 24.88 clods m^{-2}. This result is consistent with that of Gilandeh et al. (2022).
There was no statistically significant effect of the interaction between the tillage treatments and the speed of the forward speed on (N>5).

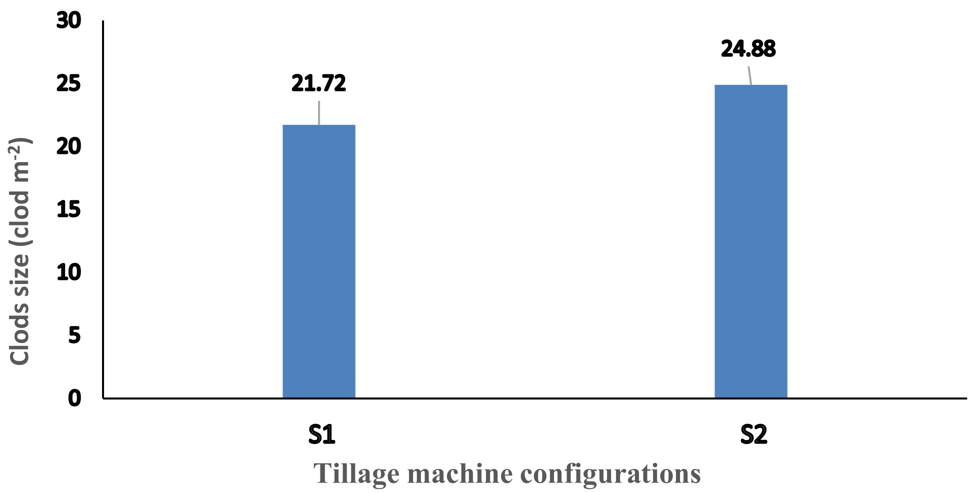

Figure 5. Effect of forward speed on clods size of soil

IV. CONCULUSION

The experiment indicated that compound tillage configurations markedly improved soil pulverization relative to the conventional chisel plow. CF2H treatment, which uses a chisel plow with sickle fins on the front and rear shanks in conjunction with a rigid harrow, consistently demonstrated the lowest soil fragmentation index, ranging from 9.20 to 34.13 mm. On the contrary, the conventional chisel plow (C) showed the highest value at 69.11 mm when operated at 2.35 km h^{-1}. Substantial relative reductions in fragmentation were observed under CF2H, ranging from 7.07% to 73.54% compared to CFH, CH, CF2, CF, and C. The forward speed significantly influenced the results; an increase from 2.35 to 3.86 km h^{-1} decreased the mean fragmentation index from 39.23 mm to 34.47 mm. The proportion of soil clods smaller than 5 cm (N>5) increased from 21.72 to 24.88 m^{-2}, indicating a positive correlation between speed and soil pulverization. The interaction between tillage configuration and speed was significant for the fragmentation index; however, it was not significant for N>5. The configuration of the CF2H compound, when paired with increased forward speeds, yielded optimal performance in soil disintegration, resulting in finer aggregates and improved soil preparation efficiency. The findings underscore the advantages of implementing compound tillage designs in comparison to traditional plows within mechanized farming systems.

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