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Effects of Vehicle and Rotational Speeds on Performance and Mechanical Damage of New a Mechanical Inter-Row Weeder

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Abstract: The performance of a mechanical weeding machine was investigated. Each unit of the machine consisted of a four bar mechanism. Effect of vehicle and rotational speeds of the machine on the performance of the system and mechanical damage were studied in four levels of speeds. Experiments were done at vehicle speeds of 1.27, 2.1, 3.5 and 5.4 *km/hr* and rotational speeds of 70, 93, 134 and 184 *rpm* in a corn field which the plants were at the 8-10-leaf stage. The results showed that the effect of rotational speed on the performance of the machine and mechanical damage of the plants was considerably compared to the vehicle speed. The vehicle speed of 5.4 *km/hr* and rotational speed of 134 *rpm* were found as the optimal speeds for cultivation by this machine, considering the maximum performance of the system and minimum damage of the plants.

Key words: Cultivator · Mechanical damage · Mechanical weeder · Rotational speed · Vehicle speed

INTRODUCTION

The proportion of people working in agricultural sectors have decreased and the production demands have increased gradually over the last several decades [1]. The performance of agricultural affairs must be improved to have higher efficiency [2]. Weeding is a part of cultivation that can be done by different methods like chemical, mechanical, physical and biological methods [1]. Mechanical weeding is one of the non-chemical customs to control weeds. There is a political interest in the European Union to increase the amount of ecologically grown products [3]. Cultivation and mechanical weeding are the main factors, which have direct effect on farm efficiency so these operations must be done in suitable conditions. In mechanical method, special tools are needed to have accurate and perfect performance. Different kind of tools is available with differences in size, function, accuracy and so on. Selection of the tools is related to kind of weed, size and topography of the farm, planting system, available power supply and some other parameters [3]. Social and economical conditions have also effect on selection of the tools, even to use manual tools. For instance there are 800 million hand tools used in Indian farms by 260 million farm workers [4]. Trowel and hoe are the manual tools, which farmers still use for weeding in small farms [5]. Hand weeding has a working quality of 100% but the cost of this method is much expensive related to other methods [6]. Also, the timing of the hand weeding is actually too late according [7]. Therefore the cultivating systems must work very close to crop rows to reduce the need for hand weeding [8].

Some people have already studied about the performance and mechanical damage of the mechanical weeding systems for cultivation. A machine vision system was developed and tested to detect and locate tomato seedlings and weed plants in a commercial agricultural environment. the results showed that the system is able to recognize the crop plants for 65 to 78% and about 5% of the weeds remained instead of crop plants [9]. The goosefoot hoe is normally used to control the intra-row weeds at the latest stage of crop development by throwing soil into the rows. This action is only possible when the crop is strong enough [10]. The results of the experiments with two way hoeing showed that a high number of passes are needed to control the weeds. Also in a research, the percentage of weeds covered by different equipments were 95% for moldboard, 48% for disc-harrow and 5% for tined cultivation [11]. A model of weeding system with two parallel toolbars named cycloid hoe was tested and it was steered manually by a hydraulic system. The performance quality of this hoe was between 60 and 67% [11]. The research about brush weeders showed that the rotational speed of the brushes can be varied from 90 to 150 *rpm* and peripheral speed of 2.7km/h

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to 4.5km/h. Another research about brush weeder showed that brush weeding has a control effect of about 80% on annual weeds at 2 to 4 leaf stage [12]. Also, a research was done about performance of mechanical weeding mechanisms to use in high speed inter-row weeding of arable crops. The results show that the powered rotary hoe worked well at all growth stages at 5 km/h but its performance declined as working speed was increased. Also, the brush weeder did not do as well as some mechanisms because its inability to penetrate and the low speed of the rotor and the ground driven rotary weeder worked well at all speeds but was less able to cope with established plant growth [13]. Torsion weeding at the 8 to 10-leaf stage uprooted 86% of the small weeds and 34% of the large weeds, whit only 5% crop loss [14]. The study about weed harrowing showed that control effect of a harrowing is 30 to 60% [8].

In organic farming, weed controlling effect by disturbance of the soil and soil biota is often minimized by non-inversion tillage [15]. In other word, organic farmers want to promote the structure of the soil by decreasing the soil destruction and they want to reduce cultivation depth.

The main objective of this research is evaluation of the performance and mechanical damage (crop injury) of a new mechanical weeding machine at different vehicle speed and selecting the best condition for the machine. The machine is introduced in methodology section.

MATERIALS AND METHODS

Cultivator: The schematic of the machine is shown in Fig. 1. The machine works based on a manual tools operation, which farmers still use in small scale for weeding and consists of a four-bar linkage mechanism [16]. One of the most important advantages of the machine is the little displacement of the top soil during weeding operation [17]. The mechanism of the system was designed to provide little movement of the blade in the soil. By starting the mechanism operation (in farm), the blade of the cultivator enters to soil, cuts the weeds and then comes out of the soil immediately. Therefore the collision of the top soil decreases in mechanical weeding by this machine. Also, the system is suitable for the fields with high moisture therefore penetrate of the cutting tools to undesirable depth is low. The machine is designed for inter-row cultivation and developed in one unit. It is shown in Fig. 1 [16]. The cultivator was designed and developed in one unit. This system can be extended to some units is mounted on one toolbar. In this study we studied one unit as the experimental tests.

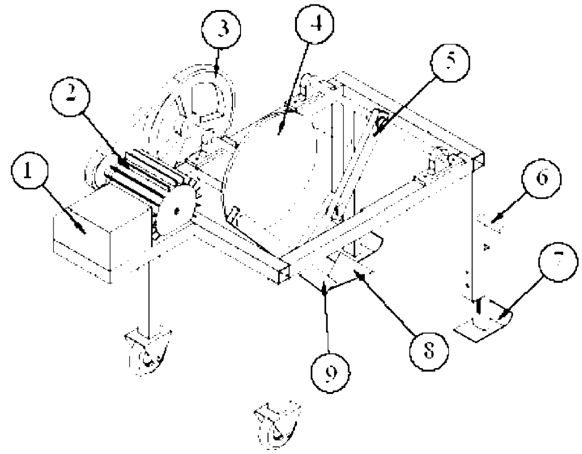


Fig. 1: A schematic of the new cultivator
1-invertor, 2- electromotor, 3- driven pulley, 4- input link, 5- follower link, 6- drawbar joints, 7- flexible shoes, 8- blade, 9- coupler link.

Field Trials: All experiments were done in a corn field in Pakdasht near Tehran-Iran. The distances were 200mm as well as the plants in each row between the rows. The plants were at 8 to 10-leaf stage. Corn variety was as single-cross 301. The soil of the field was sandy-loam and its moisture content was about 17.23% during the experiments. The steep of the field was about 0.2%. The most common weeds in the field was Field Bindweed (*Convolvulus arvensis* L.) and Ground cherries (Physalis spp.). All experiments were done in summer and the humidity of the ambient air was about 32.2%.

Machine Operation: The machine was consisted of a four-bar mechanism that the blade was placed on the coupler link (Fig. 1). Rotation of the input link causes movement of the other links as well as the blade which is located on the coupler link. Fig. 2 shows the displacement of the blade tip. The shape of the blade was V form with a cutting edge of 12cm and the end of the blade was welded to the coupler link (Fig. 2-a). The path of the blade was drawn theoretical by programming in Matlab software (Fig. 2-b).

The operation of the cultivator is shown in Fig. 3. By rotating of input link (Fig. 1-4) of the mechanism (R), the coupler link is displaced. The vehicle speed of the machine is indicated, too. As Fig. 3, coupler link is displaced in five states (Fig. 3-number 1 to 7). Therefore weeding operation can be done.

An electromotor provided the power and rotational speed of the machine for experiments. An inverter (Lenze 8300; Germany) was used to control and fix the rotational speed at different levels.

(a)

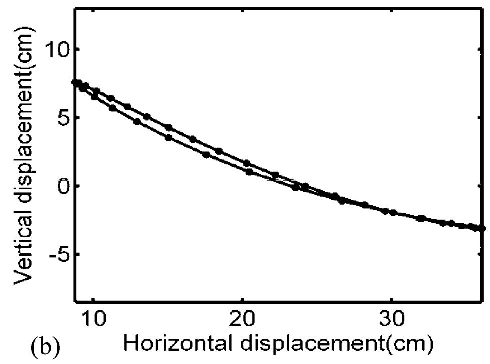

(b)


Fig. 2: The shape of the blade (a) and the path of the blade (b)

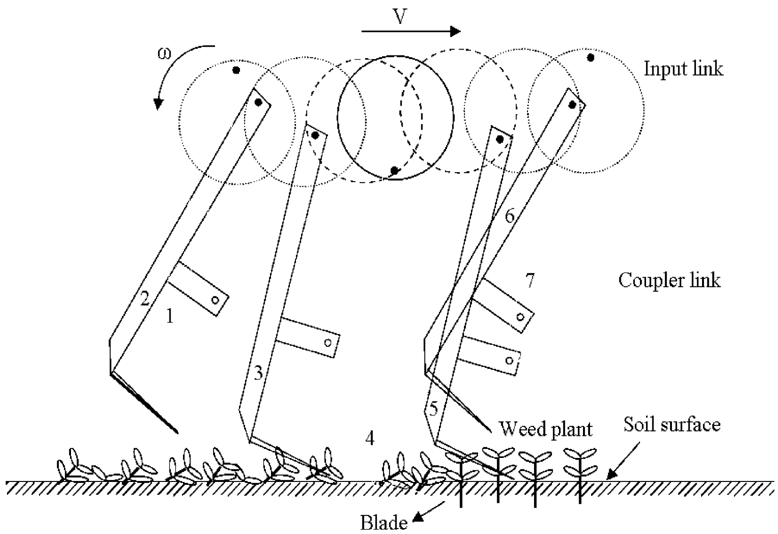


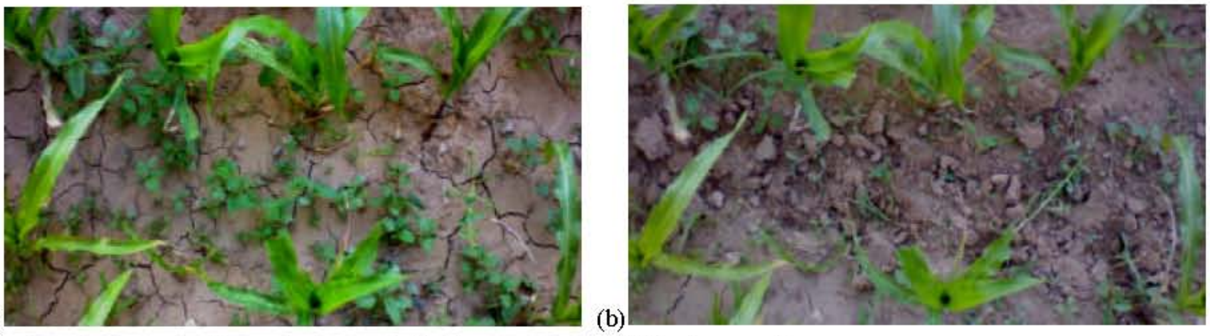
Fig. 3: The operation of the cultivator link of the mechanism

A digital photo tachometer (PROVA INSTRUMENTS INC: RM-1500/1501/1502) was used to determine the rotational speed. The movement of the machine was provided by a Goldoni tractor. The tractor was equipped with a tachometer to sense the vehicle speed. The slippage of the tractor was about 4% for all experiments. The weed control potential of inter-row weeding machine is difficult without accurate steering and implements adjustment therefore the system must be steered in accurate way.

Experimental Setup: The rotational speed was fixed at 70, 93, 134 and 184 *rpm* and the vehicle speed was taken at 1.27, 2.1, 3.5 and 5.4 km/hr for evaluation of machine performance and mechanical damage. Weed control or performance of the system was measured based on the percentage of weed density reduction and crop damage and mechanical damage as measured percentage the crops covered by soil and crop damage. All the experiments were replicated four times.

In the field, the rotation of the input shaft provided by an electromotor at selected speeds and then the machine was moved by the tractor and the weeding operation was started.

A quadrates plot was made for each experiment to determine the quantity of weed cutting and Mechanical damage. The plots marked by sticks that can withstand in mechanical weeding process. Some of the researchers used this method to evaluate the performance and mechanical damage of the mechanical weeders [18]. The dimensions of the quadrate were 200mm × 400 mm and for each experiment three plots of the quadrate were used. The number of the weeds and corn plants in the quadrate area were counted before weeding. Then the number of weeds that cut in weeding process and the damaged corn plants in the same quadrate area was counted immediately after weeding operation (Fig. 4).



(a) (b)

Fig. 4: A photograph of a quadrate area (a) before weeding and (b) after weeding

The performance of the machine was determined using Eq. 1:

$$\eta = \frac{W_e}{W_i} \times 100 \qquad (1)$$

Where η is performance of the machine, W_i is the number of the weeds in the quadrate area before weeding, W_e is the number of the cut weeds that cut in the same area after weeding.

The Eq. 2 was used to determine the mechanical damage of the corn plants by the machine:

$$MD = \frac{N_i - N_e}{N_i} \times 100 \qquad (2)$$

That MD is mechanical damage of the corn plants, N_i is the number of corn plants before cultivation and N_e is the number of the safe remained corn plants.

The experimental data were statistically analyzed using *SAS* software to determine the performance of the machine in weeding operation. Statically parameter was the vehicle speed and rotational speed as the input data and mechanical damage and performance of the machine as the out put data. The out put graphs of the data analysis were draw by *Excel* software.

RESULTS AND DISCUSSION

The effect of rotational and vehicle speeds on the performance of the cultivator is shown in Fig. 5. The performance of the cultivator increased by increasing of rotational speed at a constant vehicle speed and decreased by increasing of vehicle speed at a constant rotational speed. Table 1 shows the results of the statistical analysis carried out to examine the effect of vehicle and rotational speed on the performance of the machine. The statistical results of ANOVA indicated that the influence of vehicle and rotational speeds on the performance of the system were significant (Table 1). The interaction effects of the independent variables were also significant.

The statistical results showed that rotational speed has the greatest effect on performance of the machine (Fig. 5). The effect of the rotational speed the blade path at constant vehicle speed on is shown in Fig. 6. Matlab software was used for plotting the graphs. At a constant vehicle speed, the overlap of cultivated area was increased by increasing of rotational speed which causes a high possibility of encountering the blade and weeds. Therefore it is possible to cut nearly 100% of weeds with minimal damaged crops (Fig. 6).

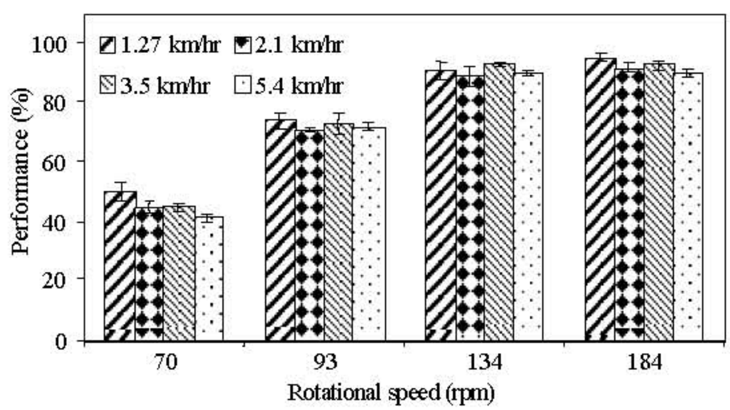


Fig. 5: Effect of rotational and vehicle speeds on the performance of the system

Table 1: Analysis of variance for the effect of rotational and vehicle speeds on the performance of the machine

Source	d.f.	SS	MS	F
Vehicle speed	3	1763.4	440.84	579.6**
Rotational speed	3	16673.7	4168.43	5480.44**
Vehicle speed × Rotational speed	9	104.8	6.55	5.62**
Error	25	19.0	0.76	
Total	49	18560.9		

d.f.: Degree of freedom; SS: Sum square; MS: Mean square; F: Statistical distribution; **significant at level 1%

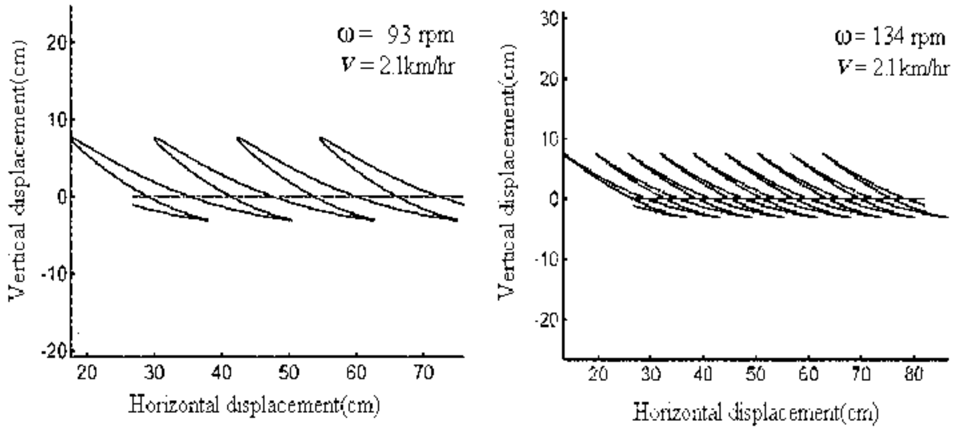


Fig. 6: Effect of rotational speed on the overlap of the system operation at constant vehicle speed

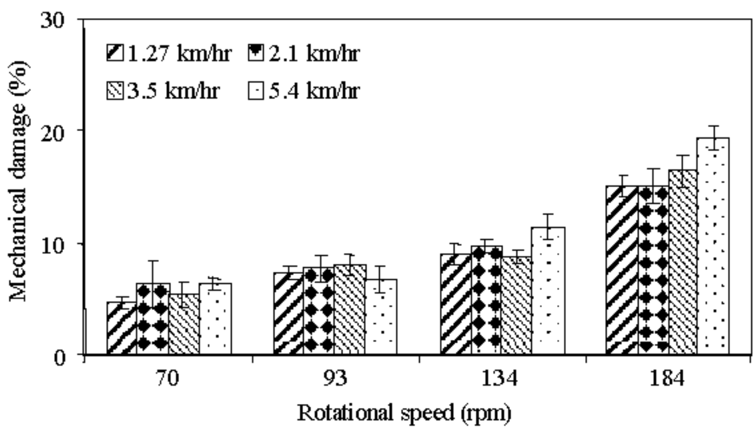


Fig. 7: Effect of rotational and vehicle speed on mechanical damage of corn plant

The Eq. 3 is proposed to estimate the performance (η (%)) of the cultivator with respect to the vehicle speed (v (km/hr)) and rotational speed (ω (rpm)).

$$\eta = 133.31 - v - \frac{5581.86}{\omega} \qquad R^2 = 0.9422 \tag{3}$$

Figure 7 shows the effect of rotational and vehicle speeds on mechanical damages of the crops during the mechanical weeding process. The mechanical damage decreased with increasing of vehicle speed at a constant rotational speed and increased by increasing of rotational speed at constant vehicle speed. Table 2 shows the correlation between the mechanical damage of corn crops and vehicle and rotational speeds. The ANOVA showed that the independent variables of rotational and vehicle speeds, significantly influenced on the mechanical damage and interaction effects between these two independent variables were significant.

Table 2 indicates that the effect of the rotational speed on mechanical damage was more significant than the effect of vehicle speed. Higher rotational speed causes more contacts between the blade tip and plants and more mechanical damages in given area. The overlap of the blade tip path causes more soil displacement and more covering of the corn plants by soil in given quadrate area.

Table 2: Analysis of variance for the effect of rotational and vehicle speed on the percentage of mechanical damage of corn plant

Source	d.f.	SS	MS	F
Vehicle speed	3	468.07	117.01	614.59**
Rotational speed	3	3227.37	806.84	4237.62**
Vehicle speed × Rotational speed	9	130.12	8.13	42.71**
Error	25	4.67	0.19	
Total	49	3830.32		

d.f.: Degree of freedom; SS: Sum square; MS: Mean square; F: Statistical distribution **significant at level 1%

The Eq. 4 is proposed to estimate the mechanical damage (*MD* (%)) by the system by considering the values of the vehicle speed (*v* (km/hr)) and rotational speed (ω (*rpm*)).

$$MD = 4.41 + 0.00\,4v^3 + 2.5 \times 10^{-5}\,\omega^{2.5} \quad R^2 = 0.9261 \qquad (4)$$

The performance of the machine was suitable for combinations of "v = 5.4km/hr, ω = 134 *rpm*", "v = 1.27km/hr, ω = 184*rpm*" and "v = 1.27km/hr, ω = 134*rpm*" (Fig. 4) and the best performance was obtained at v = 3.5 km/hr and ω = 134 *rpm* among the combinations. The results also showed that weeding at v = 2.1 km/hr causes a considerable mechanical damage of corn plants (Fig. 7) while the damages were decreased at v = 3.5 km/hr. At higher vehicle speed the required time for mechanical weeding significantly decreases which could be as an important factor for the efficiency of the system.

Rotational speed was also an important factor which has considerable effect on the quality of the weeding operation and plays an important role on the performance of the machine (Fig. 5). More mechanical damages were observed at higher rotational speeds when the vehicle speed was constant (Fig. 7). The rotational speed of 134 *rpm* is proposed for the system as the best. Therefore the performance of 94% and mechanical damage as 8% were found at vehicle speed of 5.4 km/hr and rotational speed of 134 *rpm*.

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