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EFFECT OF DESIGN PARAMETERS ON MECHANICAL HARVESTING OF CARROTS

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Abstract: The effect of design parameters on mechanical harvesting of carrot were studied by conducting experiments on a test set-up having provision to vary design variables. The test set-up consists of digging unit and soil separation unit. Design parameters - Rake angle, soil separator length and angle of soil separator were evaluated at an optimum soil moisture content of 12%. Performance parameters like percentage of carrots harvested, carrots damaged, soil separation index and power requirement were measured at different levels of design parameters and design values of different components were determined. The maximum percentage of carrots harvesting of 97.4% at 60 cm length of soil separator, rake angle of 25° and 20° angle of soil separator. Minimum percentage of carrots damage of 4.87% was obtained at 40 cm length of soil separator and 20° soil separator angle. Carrots damaged obtained in the range of 4.63 to 4.97% between 25° and 35° rake angle. The soil separation index was most affected by length and angle of soil separator. A minimum soil separation index of 0.23 can be obtained at 80 cm and 20° of length and angle of soil separator, respectively. An average power requirement for the operation of carrot harvester at a speed of 2.3 km·h^{-1} was 4.44, 5.3 and 5.75 kW at 15°, 25° and 35° of rake angle.

Key words: *carrot harvester, design parameters, rake angle, soil separation.*

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INTRODUCTION

India has achieved annual growth rate of 2.6% in total vegetable production has been recorded during the last 10 years, the average yield of vegetables in India is still lower than many Asian countries. In addition to the demand for local consumption, there is an increased demand of vegetables as one of the most potential commodities for exports [1]. Vegetables are highly perishable and need harvesting within a narrow time span, along with careful handling and proper storage before consumption or processing. In developing countries conventional method is still followed for carrot harvesting. The sequence practiced for conventional method are pulling of carrot from the bed, picking of dugout carrots, separation of green top from carrot, cleaning/washing of carrot and transportation to market (cold storage) [2]. For carrots, on an average, about 350 – 400 man-hours are required for digging and pulling out in one hectare area. Besides the quantum of labor, manual harvesting involves considerable drudgery and human discomfort. The labor has to stoop forward while digging/pulling carrot from the bed and also during picking up. Stooping posture results in a lot of bio-mechanical stresses in the back and has higher energy consumption as compared to other working positions [3]. Continuous use of bare hands for pulling out carrots may cause bruises on hands leading to infection. Both stooping and squatting working positions are not ergonomic and therefore carrot harvesting operation involves considerable human drudgery. In traditional method of harvesting, the yields are low, cost of cultivation is high and there were huge loses ranging between 30-40% of the total produce due to damage caused during harvesting, handling, storage, transport and processing [4]. By adopting mechanical harvesting manpower requirement was found 60% lower as compared to manual digging, whereas crop damage was less than 2% [5]. So there is a need for mechanization in root crop harvesting to reduce human drudgery and to reduce the cost of cultivation by 30 – 50% with better harvesting efficiency compared to manual harvesting [6]. Hence, successful harvest mechanization requires a systematic approach and involves the integrated efforts of engineers, plant breeders, plant physiologists, food scientists and others to develop technology for quality output and higher profits. Mechanical harvesting of carrots is a real challenge and truly an inter disciplinary problem.

The design parameters of any root or tuber crop harvester effects the performance of the machine. Generally the root harvester consists of digging blade and a soil separator. The tool geometry of the blade effects the digging efficiency of the harvester and draft required. The tool geometry governs by rake angle of the blade and friction angle of the soil [7]. This allows the design of simple tools on the basis of their draft force requirements and their soil cutting efficiency. The specific draft force per unit soil area and degree of soil loosening were observed to increase with relative narrowness of the tillage blades and with rake angle [8,9]. The draft increases with width, depth and rake angle of the tool. The cross-sectional area of the soil disturbed did not change appreciably with rake angle, but significant increase in draft with angle resulted in markedly diminished soil cutting efficiency [10]. The best implement design for low draft, high cutting efficiency and superior soil loosening should have rake angle of about 30° and should be fairly narrow with depth to width ratio of 2 or more [11]. The convex type blades with 20° rake angle performed better than the concave with the total recovery of 87.6 to 93.44% while it was only 77.47 to 82.14% for concave type blade and the depth of operation of potato digger should be 200 mm in order to avoid damage and loss of potatoes [12]. After digging of the roots crops, the crops had to be separated from soil mass and leave on the soil surface. This soil separation process will depend upon the length and degree of inclination of soil separator with ground surface. In case of gravity separator for separating clods from peanuts in the field, showed that with slope of 16° of the mesh belt, conveyor velocity of 0.44 meters per second, the separation effectiveness obtained was 98.6% and peanut recovery was 99.1 percent [13]. The width and pitch of conveyor, inclined at 18°, were 58 cm and 30 mm, respectively in case of potato digger showed, at slow forward speed or at higher conveyor speed there is better soil separation [14]. Very fewer efforts have been made to develop indigenous mechanized systems for carrot harvesting. Use of self propelled and tractor drawn equipment in vegetable crops, in India, is very dismal except in potato cultivation [15]. Mechanical harvesters were developed only for underground crops like potato [6,16,17], onion [18], groundnut [19,20] and cassava[21]. No information is available on mechanical harvesting of carrots on design and operational parameters and power consumption. The objective of this paper is to determine design values of carrot harvester by conducting experiments on a test set-up specially made for this purpose.

MATERIAL AND METHODS

The desired functions of carrot harvester are to dig and lift the carrots and soil mass; separate soil mass from carrots, leaving them over soil surface for collection with minimum damage to crop. There are two basic components in carrot harvester, digging blade and soil separation unit. The different variables which affect the carrot harvester were rake angle, length and angle of the soil separator. The digger was designed for harvesting carrot crop by lifting the soil and carrot without tops from the field with the help of digging unit and subsequently transferring the same onto a separating unit where carrots are separated from the soil through soil separator. After harvesting, the clean carrots are collected manually.

The functional requirements for the design of harvester were: a) The machine should dig carrots from the field. b) It should be operated by common size of tractor available in Indian farm. c) The carrots should be left uncovered over the soil surface to the rear of the tractor and they are picked up manually with minimum manual requirement. d) The carrot damage in terms of cut, crush, sliced and bruised should be as low as possible. e) The carrot should be dug up from the field in such a way that the minimum volume of soil with carrots. f) It should be simple in design and construction and efficient in digging carrots.

The experiments are conducted directly in the field where the carrots are grown. Before conducting the experiments the haulms or tops of the carrots are destroyed 3 – 6 days before harvesting by mechanical means. The experimental setup with above components was used to determine the optimum machine parameters for better performance of the harvester at optimized moisture content. The experiments were conducted as per plan, Table 1. The tests were conducted on the experimental farm in Division of Agricultural Engineering, I.A.R.I, New Delhi taking cultivar 'Nantes'. An area of 75 x 30 m^2 the test was conducted by varying different machine parameters like rake angle, length of soil separator and angle of soil separator at different levels and replicated thrice. The observations were recorded for number of carrot harvested, number of carrots damaged, weight of soil collected with carrots and power requirement. The data on performance parameters were analyzed using factorial randomized block design and statistical parameters were evaluated using Design Experts and SPSS version 16.0 software.

Table 1. Plan of experiments on test setup

Machine Variables	*Levels*	*Performance parameters*
Rake angle (degree)	$R_1 = 15$ $R_2 = 25$ $R_3 = 35$	*i. Percentage of carrot harvested* *ii. Percentage of carrots damaged* *iii. Soil separation index* *iv. Power requirement (kW)*
Length of Soil Separator (cm)	$L_1 = 40$ $L_2 = 60$ $L_3 = 80$	
Angle of Soil Separator (degree)	$A_1 = 0$ $A_2 = 10$ $A_3 = 20$	

RESULTS AND DISCUSSION

The performance parameters of the test set up of carrot harvester was evaluated at a fixed soil moisture content of 12% for three different rake angles of 15°, 25° and 35°; at three soil separator lengths of 40, 60 and 80 cm and at three angle of soil separator with horizontal surface of 0°, 10° and 20°.

Percentage of carrot harvested

All three lengths of soil separator gave comparable performance at given rake angle and angle of soil separator Fig 1. The percentage of carrot harvested increased initially with increase in rake angle and later decreased marginally. The average maximum carrot harvesting percentage of 97.79% was obtained with 60 cm length of soil separator followed by 97.66 and 97.27% with 80 and 40 cm length, respectively. In comparative terms, mean values of length of soil separators are almost same for 60 and 80 cm, whereas in case of 40 cm length of soil separator a marginally lower harvesting percentage was obtained. The other variables remaining same, carrot harvesting percentage increased with increase in rake angle; at 60 cm length of soil separator, it increased from 96.53 to 97.46% as the rake angle increased from 15° to 25°. But it remains comparatively same i.e. 97.3% when rake angle changes from 25° to 35°. For same soil separator length and angle of soil separator there is increase in the carrot harvested percentage, when rake angle increased from 15° to 25° and a very small decrease in the harvested value with increase in the rake angle from 25° to 35°. The rake angle of 25° yielded the best percentage of carrot harvested. The average percentage of carrot harvested for the length of soil separator with 60 cm at rake angle of 15° was 96.4, 96.54 and 96.56%, when angle of separator was 0°, 10° and 20°, respectively. This shows a comparatively small increase in carrot harvested percentage with increase in angle of soil separator.

The influence of soil separator angle was less pronounced in all combinations of rake angle and length of soil separator. Rake angle influenced carrot harvesting significantly at 1% level of significance (Tab. 2.). Hence, it could be inferred that in the given range of the variables, highest percentage of carrots harvested was observed at 25° rake angle, 60 cm length of soil separator and 20° of soil separator angle. The pair wise comparison of influence of length of soil separator and rake angle on carrot harvesting percentage indicated that the 60 cm gave higher harvesting percentage in comparison to other two lengths and 25° rake angle was observed higher harvesting percentage than other two levels of rake angles as the mean difference was found positive for both variables in pair wise comparison at 5% level of significance. Hence, it could be inferred that in the given range of the variables, highest percentage of carrots harvested was observed at 25° rake angle, 60 cm length of soil separator and 20° of soil separator angle.

Table 2. Descriptive statistics of percentage of carrot harvested for different level of variables

Levels of variables	*Percentage of carrot harvested (%)*		*CV (%)*	*F – Value*
	Range	*Mean*		
Length of soil separator (cm)				
40	96.40–97.66	97.07	0.47	0.76
60	96.53–97.79	97.18	0.46	
80	96.95–97.72	97.11	0.12	
Rake angle (degree)				
15	96.40–96.98	96.69	0.23	11.3**
25	97.18–97.79	97.4	0.22	
35	97.18–97.14	97.29	0.08	
Angle of soil separator (degree)				
0	96.40–97.46	97.03	0.36	0.18
10	96.54–97.51	97.12	0.34	
20	96.86–97.79	97.21	0.43	

*** significant at 1% level of significance*

The percentage of carrot damaged increased with increase in length of soil separator and decreased with increase in rake angle and soil separator angle (Fig 1). The average percentage of carrots damaged with 40, 60 and 80 cm length of soil separator was observed as 4.87, 5.44 and 5.51% with corresponding coefficient of variation of 16.83, 14.7 and 12.5%, respectively (Tab. 3). The damage percentage in case of 40 cm soil separator length was found lower due to less travel time of carrots with soil, which reduces the damages of carrots due to friction with soil mass. Carrots damage percentage decreased with increase in rake angle; at 80 cm length and 0° angle of soil separator, it decreased from 6.57 to 5.41% as the rake angle increased from 15° to 25°. But it remains comparatively same i.e. 5.11% when rake angle changes from 25° to 35°. The rake angle of 35° yielded the best percentage of carrot harvested but there is no large difference when compared to 25°. The average percentage of carrot damaged for the length of soil separator with 60 cm at rake angle of 15° was 6.86, 6.48 and 5.89%, when angle of separator was 0°, 10° and 20°, respectively. This shows a comparatively decrease in carrot damage percentage with increase in angle of soil separator.

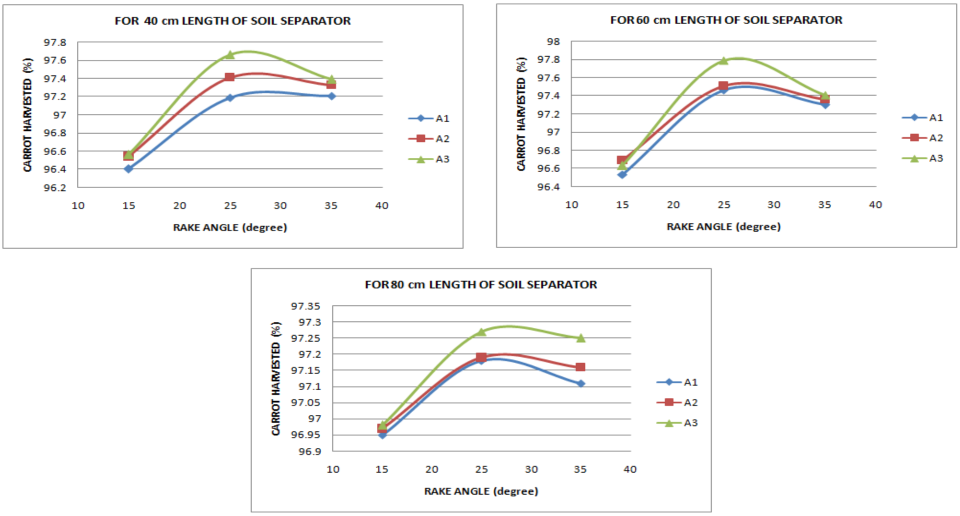

Figure 1. Effect of different variables on carrots harvested

Percentage of carrots damaged

The pair wise comparison of influence of soil separator length and rake angle on percentage of carrots damaged indicated that lower damage percentage was observed at 40 cm in comparison to damage percentage obtained at other two levels of soil separator lengths and 35° of rake angle was observed lower damage percentage than other two levels of rake angles, pair wise comparison was significant at 5% level of significance. There is no much difference in the carrot damage percentage between 25° and 35° of rake angle.

Table 3. Descriptive statistics of percentage of carrot damaged for different level of variables

Levels of variables	*Percentage of carrot damaged (%)*		*CV (%)*	*F – Value*
	Range	*Mean*		
Length of soil separator (cm)				
40	3.09 – 6.26	4.87	16.83	2.18
60	4.45 – 6.86	5.44	14.7	
80	4.86 – 6.57	5.51	12.5	
Rake angle (degree)				
15	5.54 – 6.86	6.86	6.25	42.74**
25	4.35 – 5.45	4.94	7.48	
35	3.99 – 5.11	4.63	8.42	
Angle of soil separator (degree)				
0	4.23 – 6.86	97.03	0.36	0.98
10	4.31 – 6.48	97.12	0.34	
20	3.99 – 6.31	97.21	0.43	

*** significant at 1% level of significance*

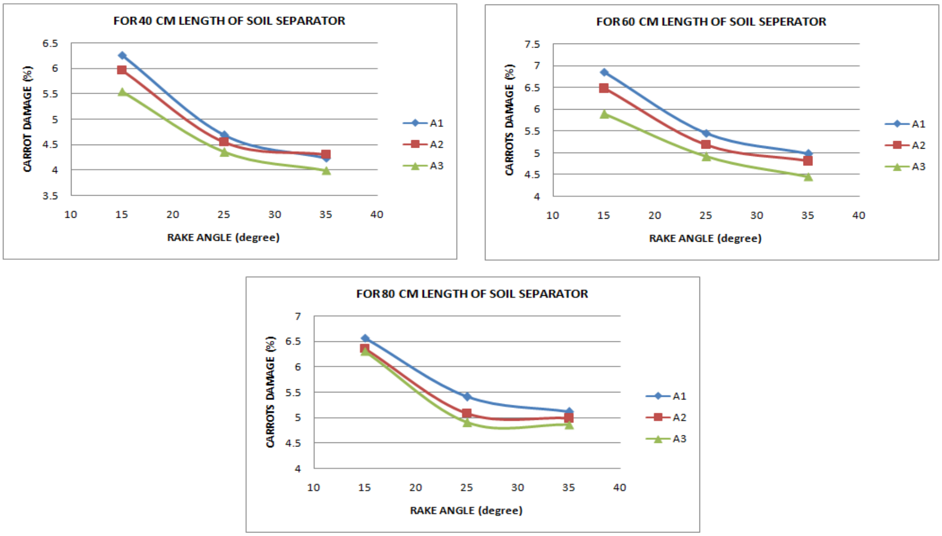

Figure 2. Effect of different variables on carrots damage

Soil separation index

After digging of carrots the soil was to be separated from carrots with the help of soil separating unit. To measure the efficiency of the carrot harvester to separate the soil, soil separation index was defined. For better separation of soil from carrots the value of soil separation index should be minimum. Soil separation index is a function of moisture content and travel time of soil over soil separator. Travel time of soil is further depends upon length of soil separator and angle of soil separator with horizontal surface.

Table 4. Descriptive statistics of soil separation index for different level of variables

Levels of variables	*Soil separation index*		*CV (%)*	*F – Value*
	Range	*Mean*		
Length of soil separator (cm)				
40	0.26 – 0.33	0.29	9.3	234.74**
60	0.21 – 0.26	0.23	6.08	
80	0.21 – 0.26	0.23	6.52	
Rake angle (degree)				
15	0.21 – 0.32	0.24	14.63	1.52
25	0.21 – 0.32	0.24	14.11	
35	0.22 – 0.33	0.26	12.6	
Angle of soil separator (degree)				
0	0.23 – 0.33	0.27	14.8	134.04**
10	0.22 – 0.30	0.25	12.4	
20	0.21 – 0.26	0.23	29.8	

*** significant at 1% level of significance*

The soil separation index increased initially with increase in length of soil separator and later remained almost same (Fig 3). The average minimum soil separation index of 0.21 was obtained with 60 cm length of soil separator followed by 0.22 and 0.26 with 80 and 40 cm length, respectively. The average soil separation index were very closely distributed for two levels of soil separators length, the mean values of separation index were 0.22 and 0.23 for 60 and 80 cm length of soil separators, respectively. Therefore, it could be inferred that, 60 and 80 cm lengths of soil separator can be used for effective soil separation. Soil separation index increased from 0.23 to 0.26 as the rake angle increased from 25° to 35°. But it remains same i.e.0.23 when rake angle changes from 15° to 25°. However, in case of other two lengths of soil separators i.e. 40 and 80 cm, same pattern was observed. Based on mean values, the soil separation index at 15° and 25° did not vary much for both rake angles. But there is increase in separation index at 35° rake angle i.e.0.26 compared to other two levels. The soil separation index decreased with increase in soil separator angle, it decreased from 0.32 to 0.26 as the soil separation index increased from 0° to 20° at 40 cm length of soil separator. The average soil separation index for the length of soil separator with 60 cm at rake angle of 15° was 0.24, 0.23 and 0.22%, when angle of separator was 0°, 10° and 20°, respectively. The influence of soil separator angle was more pronounced in all combinations of rake angle and length of soil separator.

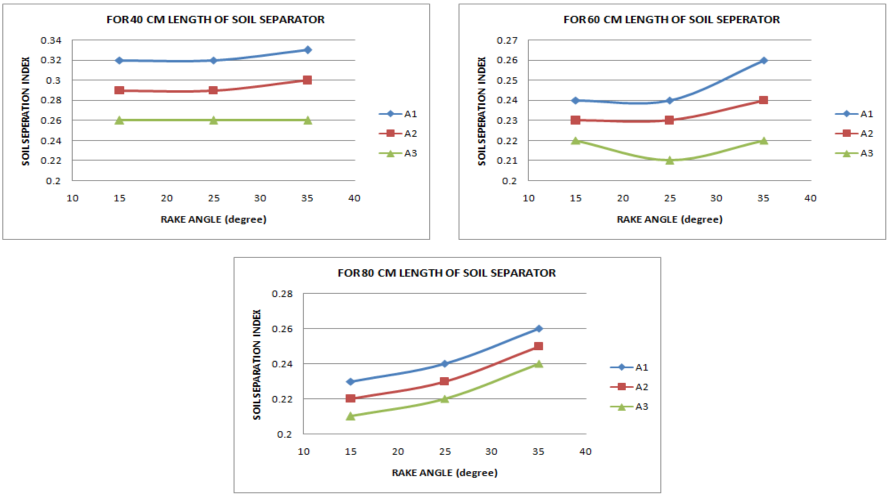

Figure 3. Effect of different variables on soil separation index

The length of soil separator and angle of soil separator was effecting soil separation process significantly at 1% level of significance. The pair wise comparison of influence of length and angle of soil separator indicated that the 60 cm gave lowest soil separation index in comparison to other two lengths and 20° angle of soil separator observed higher soil separation than other two levels of soil separator angle as the mean difference was found negative for it in pair wise comparison at 5% level of significance. The length of soil separator influenced soil separation index most, followed by soil separator angle as indicated by F-values (Table 4). Hence, it could be inferred that in the given range of the variables, lowest soil separation index was observed at 25° rake angle, 60 cm length of soil separator and 20° of soil separator angle.

Power requirement

Power is the main constraint for any digging operation. Power requirement will depend upon the depth of operation, soil metal friction and tool geometry.

Table 5. Descriptive statistics of Power requirement for different level of variables

Levels of variables	*Power requirement (kW)*		*CV (%)*	*F – Value*
	Range	*Mean*		
Length of soil separator (cm)				
40	4.29 – 5.70	5.04	10.7	0.32
60	4.45 – 5.80	5.10	8.6	
80	4.22 – 5.83	5.12	10.3	
Rake angle (degree)				
15	4.22 – 4.72	4.44	3.55	27.09**
25	5.05 – 5.70	5.30	4.38	
35	5.36 – 5.80	5.57	2.51	
Angle of soil separator (degree)				
0	4.51 – 5.80	5.19	9.60	0.49
10	4.34 – 5.61	5.07	8.70	
20	4.22 – 5.57	4.96	8.90	

*** significant at 1% level of significance*

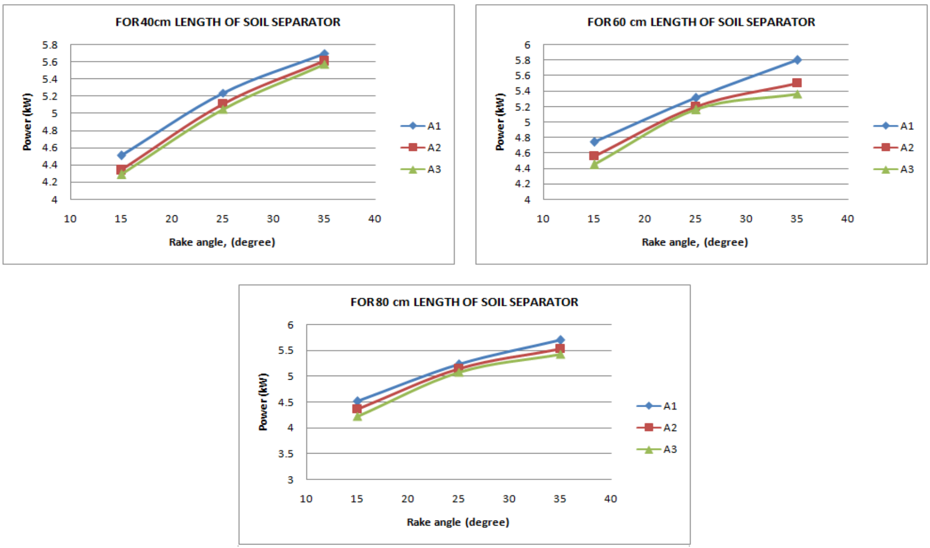

Figure 4. Effect of different variables on power requirement

The power requirement increased with increase in rake angle and very small change with increase in length and angle of soil separator. The average power requirement at 15°, 25° and 35° rake angle was 4.44, 5.3 and 5.57 kW with coefficient of variation 3.55, 4.38 and 2.51%, respectively (Table 5). The power requirement in case of 15° rake angle was least followed by 25° and 35°. The power requirement was almost same at three selected levels of angle of soil separator. The average power consumption was found 5.19, 5.07 and 4.96 kW which are almost same at soil separator angle of 0°, 10° and 20° with coefficient of variation 9.6, 8.7 and 8.9%, respectively. Similarly, for different length of soil separator the power required is almost same i.e. 5.04, 5.1 and 5.12 kW with coefficient of variation 10.7, 8.6 and 10.3%, at 40, 60 and 80 cm length.

CONCLUSIONS

- The mechanical carrot harvester gave an average maximum percentage of carrots harvesting of 97.18, 97.4 and 97.21% at 60 cm length of soil separator, rake angle of 25° and 20° angle of soil separator, respectively.
- The average minimum percentage of carrots damage of 4.87% was obtained at 40 cm length of soil separator and 5.02% at 20° soil separator angle. Carrots damaged obtained in the range of 4.63 to 4.97% between 25° and 35° rake angle.
- Soil separation was maximum at average minimum soil separation index of 0.24 was obtained at all rake angles and 0.23 when angle of soil separator was at 20° with horizontal surface. Soil average soil separation index is obtained same for both 60 and 80 cm length of soil separator.
- Power requirement is very less effected by length and angle of soil separator, so any of the levels can be considered. As the rake angle increases, power requirement increased. An average power requirement was 4.44, 5.3 and 5.75 kW at 15°, 25° and 35° of rake angle.

Overall, 60 cm length of soil separator, 25° of rake angle and 20° of soil separator angle was considered for efficient carrot harvesting at 12% optimum moisture content.

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UTICAJ PARAMETARA KONSTRUKCIJE NA MEHANIČKO UBIRANJE ŠARGAREPE

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Sažetak: Uticaj parametara konstrukcije na mehaničko ubiranje šargarepe proučavan je izvođenjem ogleda na test modelu uz promene vrednosti promenljivih veličina. Model za testiranje se sasoji od kopača i jedinice za izdvajanje zemlje. Parametri konstrukcije – ugao grablji, dužina separatora zemlje i njegov ugao su ocenjivani pri optimalnoj vlažnosti zemljišta od 12%. Parametri kao što su procenat ubranih šargarepa, oštećene šargarepe, indeks odvajanja zemlje i porebna snaga su mereni na različitim nivoima i određene su vrednosti različitih komponenti. Maksimalni procenat ubranih šargarepa od od 97.4% sa dužinom separatora od 60 cm, uglom grablji od 25° i uglom separatora od 20°. Minimalni procenat oštećenja šargarepa od 4.87% bio je postignut sa dužinom separatora od 40 cm i uglom separatora od 20°. Oštećenja šargarepa nalazila su se u opsegu od 4.63 do 4.97%, sa uglom grablji od 25° do 35°. Na indeks izdvajanja zemlje najviše su uticali dužina i ugao separatora zemlje. Minimalni indeks separacije od 0.23

se može ostvariti dužinom i uglom separatora od 80 cm i 20°, redom. Prosečna potrebna snaga za rad kombajna za šargarepu, pri radnoj brzini od 2.3 km·h^{-1}, bio je 4.44, 5.3 i 5.75 kW za uglove grablji od 15°, 25° i 35°.

Ključne reči: *kombajn za šargarepu, parametric konstrukcije, ugao grablji, odvajanje zemlje*

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