Original Research Article

OPTIMIZING CARROT HARVESTING MACHINE DESIGN: INCORPORATING SOIL AND CROP PARAMETERS

ABSTRACT

Mechanization in carrot harvesting is essential to save time and reduce labour-intensive work as well as harvesting costs. The aim of the study was to determine the soil properties and plant parameters for designing an appropriate carrot (cv: Madhuvan) harvesting machine, that would address the challenges faced by farmers. The physical characteristics of the soil and carrot plants significantly influence the design of the digging, conveying, de-topping, and collection units.These parameters include the digging depth, blade angle, forward speed, plant catch height, conveyor belt spacing, conveyor speed, and collection unit size. The mean values of shoot length, root length and shoot diameter at top of carrot were 62.5 cm, 26.5 cm, and 3.72 cm, respectively. The average weight of carrot root was 61.85 g. The mean values for spacing between ridges, height of ridge and width of ridge were 44.3 cm, 12.1 cm, and 42.8 cm, respectively. The mean number of carrots per meter row length was observed as 41. The black cotton soil with a mean moisture content of 19.77% (d.b.) at the harvesting stage of carrot, and its bulk density measured 1.31 g cm^{-3}, while the average value of soil resistance was 2153.5 kPa. By utilizing this data, the machine's design can be fine-tuned to ensure effective digging performance while minimizing any potential damage to the carrot roots during the harvesting.

Keywords: *Carrot, Cultivation, Harvesting,Digging, Design, Conveying, Soil Strength.*

1. INTRODUCTION

Carrot (*Dacus carota* L.) is very important vegetable root crop. This is a versatile vegetable native to Europe and south-western Asia. The edible portion of a carrot is the taproot, but it was first cultivated for their aromatic leaves and seeds (Rani *et al.,* 2018). It is an orange or red-white blend in colour, with a crisp texture when it is fresh. Carrots are rich sources of dietary fibre and calcium pectate as well as beta-carotene, which the body converts into vitamin A, B and C. The carrot can be consumed in fresh state (as salad ingredient), as processed canned peeled carrot or as a dehydrated product usually as a constituent of soup powder and flavouring for convenience foods. Carrot is widely recommended by physicians for innumerable medicinal purposes. Its pectin fibre is beneficial in lowering the cholesterol level of the body (Gojiya*et al.,* 2022). China is the largest carrot production country in the world, and itsannual production of carrots estimated to be 17.3 million tons between 1994 and 2014. In India, the cultivated area of carrot in 2018-19 was 108 thousand ha with a production of 1865 thousand metric tons. The major carrot growing states in India are Haryana, Punjab, Uttar Pradesh, Bihar, Madhya Pradesh, Assam, Karnataka, and Jammu & Kashmir (APEDA, 2020). However, in Haryana it was 17.28 thousand ha & 266.82 thousand metric tons, respectively

(Carrotmuseum, 2021). While in Gujarat it was 0.023 thousand ha & 0.265 thousand metric tonnes, respectively (Agricoop, 2020).

The cultivation of vegetables has a significant impact on the economic well-being of farmers. However, many farmers still rely on traditional tools and methods, which leads to various challenges. These challenges include low crop yields, high cultivation costs, and substantial losses, typically ranging between 30-40% of the total produce. These losses occur due to damage inflicted during different stages such as harvesting, handling, storage, transport, and processing. Addressing these issues is crucial for improving the economic condition of farmers and maximizing the potential of vegetable crops (Chavda *et al.,* 2022). If improved hand tools, machines, and modern technologies are used in the action and processing of crops, crop yields could be increased substantially, and losses could be minimised to a great extent (Srivastava, 2000).

Carrot is an ancient cool season root vegetable grown extensively in various countries particularly during winter season in tropical regions while during summer season in temperate countries (Kalra *et al.,* 1987). Carrots are usually sown in the month of October/November with a seed rate of 5 - 6 kg/ha depending on variety and sowing method. There are two methods for sowing on flat surface and raise bed. Carrots are grown on raised beds at a height of 15 – 20 cm and row to row spacing is about 30 – 45 cm. The crop becomes ready for harvesting after 90 – 110 days of sowing and normally it is done at a tender stage to avoid decay (Chadda, 2006). Yield varies with season, climate, varieties, fertility of soil, irrigation facility, etc.

Carrots grow on ridges and are harvested after loosening from the soil surface and pulling out roots by grasping the top. For harvesting carrots manually in one hectare, an average of 250 – 300 man-hours are required which is very expensive for farmers besides the quantum of labor, manual harvesting involves considerable drudgery and human discomfort. During peak time sufficient labors are not available that delay the harvesting and thus result in damage and loss to crop (Gaadhe and Tiwari, 2022).

1.1 DESIGN CONSIDERATION

The design and manufacturing of the carrot harvesting machine considered the functioning of existing diggers and conveyors, such as those used for carrots, groundnuts, potatoes, onions, and grains. These existing mechanisms were considered in order to enhance the range of features associated with the efficient and effective design of the carrot harvesting machine. The machine efficiently carries out its intended task with minimal power and labor requirements. The development of the carrot harvesting machine involved implementing basic manufacturing and engineering procedures, resulting in a machine that is perceived as low-cost, easy to operate, transport, and construct for carrot harvesting. Locally available materials with acceptable strength and stability were used in manufacturing the various parts of the carrot harvesting machine.

2. MATERIAL AND METHODS

2.1 Location of Experiment

Junagadh (21.5° N,70.5° E and 60 m AMSL) is in the foothills of Mount Girnar in the south Saurashtra agro climatic zone of Gujarat, represents an irrigated, mechanized and input intensive cropping area of the Indo Gangetic Plain region. The climate of Junagadh is semi-arid subtropical, with dry hot summers and cool winters. Average annual rainfall is around 860 mm and over 75% of this is received through the southwest monsoon during July to September.

2.2 Measurement Methods

To minimize damage and ensure effective harvesting of carrot crops using machines, a principle has been employed. The principle focuses on reducing the aggressive impact of the digging tool on the carrot crops as it moves away from the root. This is done by reducing the amount of soil that gets stuck to the digging tool, as this increases the chances of direct contact between the tool and the carrot root, resulting in damage. The primary objective of this study was to achieve improved digging while minimizing damage to the carrot root. This objective was accomplished by measuring various soil and crop parameters. In this section the used equipment's and measurement techniques adopted during the investigation were described.

2.3 Soil parameters

The soil properties play a crucial role in designing any digging system, as they have a direct influence on machine parameters. The soil moisture content, bulk density, and soil resistance were identified as particularly significant factors that impact the performance of the digging system. These factors affect the digging efficiency and power requirements when operating the machine in real field conditions. Therefore, understanding and considering these soil properties are essential for optimizing the design and performance of the digging system.

2.3.1 Type of soil

The type of soil affects the draft requirement, as well as the maximum penetration depth of the digging tyne. Particle size analysis was conducted on five different soil samples taken from different locations of the experimental plot. The majority of soils in Saurashtra region are clayey (fine textured) and well drained. Some scattered parts have excessive drainage. Soil type in Junagadh district (Saurashtra region) are black cotton soil which is shown in Fig.1. The water levels are relatively shallow (5 to 20 m below the ground level) over the Junagadh district. An international pipette method (Gee and Bauder, 1986)was employed for the particle size analysis. The digging tyne of the carrot crop harvesting machine interact with soil to dugout the carrot root. Therefore, soil properties directly affect the digging performance of carrot crop harvesting machine. Hence the Soil strength, Soil moisture content and Soil bulk densitywere evaluated at upper layer of soil (0-30 cm) before designing the carrot crop harvesting machine.

Fig. 1 Soil of Saurashtra region

2.3.2 Soil moisture content

The soil samples were taken from different locations in the experimental field and moisture content was determined by oven drying method. Samples were placed in oven for 24 h at 106 ºC temperature and weights of dried samples were taken (Fig. 2). The method for the determination of water content, recommended by the Indian standards institution (I.S.I.), as set out in "IS: 2720(Part-II) – 1964: Methods of test for soils Part-II Determination of Moisture Content" was followed (Gojiya*et al.,* 2022). The moisture content of soil sample on dry basis was determined by the following formula:

$$\textbf{Moisture content } (M_d)\ (\%) = \frac{\text{Initial weight of soil sample (gm)} - \text{Final weight of soil sample (gm)}}{\text{Final weight of soil sample (gm)}} \times 100$$

Fig. 2 Soil moisure content mesurement

2.3.3 Soil bulk density

Bulk density serves as a measure of soil compaction and overall soil vitality. It has significant implications for various soil processes and influences key factors such as infiltration, rooting depth, available water capacity, soil porosity, plant nutrient availability, and the activity of soil microorganisms. These parameters, in turn, play a crucial role in determining soil productivity. It was determined by core cutter method. A core cutter of 1000 cc was used for soil sampling from different locations. The soil inside the core cutter was weighed after oven drying and bulk density was found by dividing the weight of soil by volume of core cutter (IS: 2720 – 1983). The following equation was used to determine the bulk density of soil sample. Figs. 3and 4 show the collection of soil samples for bulk density determination (Gojiya*et. al,* 2022).

$$\text{Soil bulk density } \boldsymbol{(\gamma)} = \frac{\textbf{weight of the soil sample (g)}}{\textbf{Volume of core cutter (cm3)}}$$

Fig. 3 Soil sample collect by core cutter method

Fig. 4 Weight measurement of soil sample

2.3.4 Soil strength

Soil strength is a measure of the capacity of soil to resist deformation and refers to the amount of energy that is required to break apart aggregates or move implements through the soil. It is measured in Pascal's (kPa) with the help of a cone penetrometer, which indicate penetration resistance. With regard to grapevine growth, soil strength affects the ability of the roots to penetrate the soil. Soil strength is influenced by several factors, like soil water content, texture, and structure of soil, etc. It was relevant in the determination of the power requirement of the machine (ASAE: S313.3).

2.4 Crop Parameters

The assessment of crop parameters, including shoot length, root length, diameter of the root at the top, number of roots per meter length, and root weight, plays a significant role in influencing the effectiveness of the digging and conveying unit during the operation. These diverse crop parameters were obtained prior to the carrot crop's harvest.

2.4.1 Shoot length and root length

The length of the carrot shoot played animportant role in assessing how easily the carrots could be harvested and conveyed. On the other hand, the length of the carrot root was important in determining the depth of operation and digging angle of the carrot harvesting machine. To gather the data, ten carrots were randomly selected from each plot, and their shoot and root lengths were measured using a measuring tape (Fig. 5).

Fig. 5 Mesurement of the shoot and the root length of the carrot crop

2.4.2 Diameter of shoot

The measurement of the carrot shoot diameter at the top was essential for determining the appropriate clearance between the two rotating belts of the conveying unit. This clearance was necessary to effectively hold the leaves of the harvested carrots and convey them to the designated row. In the field, ten carrots were chosen randomly, and their shoot diameter at the top was measured using a Digital Vernier caliper(Fig. 6).

Fig. 6 Mesurement of shoot diameter of carrot crop

2.4.3 Weight of carrot

The weight of the carrot was relevant to know if the leaves caught by the rotating belt and pulley of the conveying unit would be able to hold the weight of the carrot without breaking and would be able to convey the harvest carrot into the row. Ten carrots were randomly selected, and the average weight of a carrot was measured by a weighing machine.

2.4.4 Depth of carrot

The measurement of carrot depth was taken by starting at the ridge's surface and extending to the tip of the carrot root. This depth measurement was important in determining the appropriate range of angles for the digging unit. At ten randomly selected locations within the area, data regarding the depth was collected. After clearing away the soil from the side of the carrots, a measuring scale was used to obtain the depth measurements.

2.4.5 Ridge spacing

The distance between two ridges was measured by calculating the center-to-center distance. This measurement was important in designing the digging unit, particularly in determining the appropriate spacing between the tyne and the tractor tire. It was also beneficial for maneuvering the tractor smoothly between the rows.

2.4.6 Height of ridge

The vertical distance between the digging tines and the conveying unit was influenced by the height of the ridge. To obtain this measurement, the height of the ridge was assessed at ten randomly selected locations using a depth measurement scale (Fig. 7).

Fig. 7 Measurements of height of ridge

2.4.7 Width of ridge

The width of the ridge played a crucial role in determining both the overall width of the digging unit and the spacing between two tines. The width of ridge was measured at ten random places with measuring tape in the field.

2.4.8 Numbers of carrots per meter row length

The traditional or old method of sowing carrot seeds involves both broadcasting and dropping the seeds behind a plow in a field. As a result, the carrots grow on ridges but in varying numbers. Therefore, it was necessary to count the number of carrots. The number of carrots per meter of row length was important in determining the conveying speed, length of the conveyor, and holding capacity of the conveying unit. The counting was carried out randomly in a one-meter row at ten different locations in the experimental field (Fig. 8). This count was performed before the cropwas harvested. To accurately determine the total number of carrots in a one-meter row, the carrots were separated after harvesting, as shown in the accompanying Fig. 9.

Fig. 8 Marking of row per meter length

Fig. 9 Number of carrots per meter row length

3. RESULTS AND DISCUSSION

The design, development, and performance of the carrot crop harvesting machine were influenced by various parameters related to the soil and carrot crop. In this section, we present the results and discuss the implications of these parameters. The soil parameters such as depth, space between ridges, and ridge height were measured to understand their impact on the machine's design and performance. Additionally, the number of carrots per meter row length was counted to evaluate the conveying speed, conveyor length, and holding capacity of the machine. These results provide valuable insights into the relationship between soil and crop parameters and the effectiveness of the carrot crop harvesting machine. Through a thorough discussion of these findings, we aim to highlight the significant implications for future advancements in carrot harvesting.

3.1 Soil Properties at Harvesting Stage

The black cotton soil present in the experimental field exhibits distinct physical and mechanical properties, which are elaborated upon as follows:

3.1.1 Soil moisture

Soil moisture is an essential factor for successful carrot harvesting, as excessively dry or wet soil can influence the ease of carrot extraction. High moisture content might lead to soil clumping, while low moisture content can cause soil compaction and make it harder to remove carrots. Prior to each experiment, the soil moisture content was assessed at ten different locations and at varying intervals to examine its impact on other parameters. The moisture content of the soil, measured on a dry basis, ranged from 16.45% to 22.19%, with an average moisture content of 19.77%, with a standard deviation of 2.43% at the time of harvesting. These findings closely aligned with the results reported by Ghali (2019) and Behera *et al.* (2023). The specific observations of moisture content (dry basis) during the harvesting stage in the experimental field are presented in Table 1.

3.1.2 Bulk density

To investigate the impact of soil bulk density on other parameters, measurements were taken at ten different locations within the experimental plot, with replications. The results revealed that the bulk density of the soil ranged from 1.26 to 1.35 g/cm³, with an average bulk density of 1.31 g/cm³, with a standard deviation of 0.04 g/cm^3 as indicated in the accompanying table. It can affect the machine's ability to extract carrots from the soil. Higher bulk density values may require the machine to exert more force to uproot the carrots.

3.1.3 Soil strength

Soil strength, assessed with a cone penetrometer, serves as a measure of soil hardness. Before commencing the experiment, soil strength was randomly measured at ten different locations to examine its influence on other parameters. The observed values ranged from 2010 kPa to 2295 kPa, with an average value of 2153.5 kPa and it has a standard deviation (SD) of 95.36 kPa. The standard deviation indicates the variability or spread of the soil strength values around the average. Higher soil strength values can pose challenges for the carrot harvesting machine to efficiently penetrate and harvest carrots.

Table 1: Soil parameters at harvesting stage

Sr. No.	Particular	Average value	Max.	Min.	SD
1	Moisture content (%)	19.77	22.19	16.45	2.43
2	Bulk density (g/cm^3)	1.31	1.35	1.26	0.04
3	Soil Strength(kPa)	2153.5	2295	2010	95.37

Designing a carrot harvesting machine that can effectively handle different soil conditions within the ranges provided in the table will be crucial for its successful operation.

3.2 Crop Parameter at Harvesting Stage

The design and performance of the carrot harvesting machine are expected to be influenced by the physical properties of the carrot crop. These properties have a direct impact on the digging, picking, and conveying efficiencies, as well as the power requirements for operating the machine, especially in relation to the soil properties.

The shoot length of the carrot crop was measured within a range of 39 cm to 81 cm. From a randomly selected sample of carrots, the average shoot length was found to be 62.5 cm. The standard deviation is 13.21 cm, indicating the variability of shoot length among carrot plants.The average root length is 26.5 cm, with a maximum of 37 cm and a minimum of 16 cm. The standard deviation is 6.59 cm. Notably, the depth of the carrot crop in the soil bed was observed to be equal to the root length of the carrots, which is a crucial factor to consider in the machine's design to ensure effective harvesting.

Regarding the root diameter at the top of the carrots, it was found to be within the range of 1.8 cm to 6.6 cm, with an average of 3.72 cm. The standard deviation is 1.49 cm. The weight of individual carrots ranged from 28.5 g to 94.02 g, with an average weight of 61.85 g. These weight and diameter measurements are essential for designing a machine that can handle carrots of different sizes efficiently.

The average spacing is 44.3 cm and standard deviation is 2.06 cm, with a maximum of 47 cm and a minimum of 40 cm. Additionally, the height of the ridges ranged from 10 cm to 15 cm, with an average height of 12.1 cm, while the width of the ridges measured from 40 cm to 48 cm, with an average bottom width of 42.8 cm. The standard deviation is 2.30 cm. These ridge dimensions play a significant role in the machine's maneuverability during harvesting.

In the experimental field, it was found that the average number of carrots per meter of row length is 41.6, with a maximum of 60 and a minimum of 22. The standard deviation is 13.03, as indicated in the accompanying Table 2. This information is crucial for determining the machine's capacity and efficiency during the harvesting process.

Table 2: Measurement of physical parameters of carrot crop and soil bed

Sr. No.	Particular	Average value	Max.	Min.	SD
1	Shoot length (cm)	62.5	81	39	13.21
2	Root length/depth of crop (cm)	26.5	37	16	6.59
3	Root diameter at top of carrot (cm)	3.7	6.6	1.8	1.49
4	Weight (g)	61.9	94.2	28.5	21.60
5	Spacing between ridges (cm)	44.3	47	40	2.06
6	Height of Ridge (cm)	12.1	15	10	2.18
7	Width of Ridge (cm)	42.8	48	40	2.30
8	No. of carrots per meter row length	41.6	60	22	13.03

The table provides important information about various parameters related to carrot growth and distribution in the field. The design of the carrot harvesting machine should consider these parameters to ensure efficient and effective harvesting while accommodating the natural variability present in carrot crops.

4. CONCLUSIONS

The goal of this research was to identify the soil properties and plant characteristics, specifically focusing on the Madhuvan variety of carrots, to facilitate the optimal design of a carrot crop harvesting machine. By analyzing the soil and crop parameters, the study aimed to determine the machine dimensions and the necessary forces required for efficient operation in the field.

The above findings suggest several essential points for the design of a carrot harvesting machine. Firstly, the machine can either be side-mounted or front-mounted of the tractor. Secondly, it should have two tynes and be capable of digging up to a depth of 35 cm. Thirdly, the conveying belt should be more than 2.5 meters long and positioned 5 cm above the ground surface. Additionally, the spacing between two conveying belts should be less than 5 cm, and the gap between the two tynes should be approximately 25 cm. By utilizing this data, the machine's design can be fine-tuned to ensure effective digging performance while minimizing any potential damage to the carrot roots during the harvesting.These findings offer valuable insights for the improvement of carrot harvesting technology and can guide future advancements in this field.

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