CHAPTER II

REVIEW OF LITERATURE

Earlier studies carried out with respect to root crop harvester has been outlined in this chapter. The reviews are presented under following sub heads;

2.1. Soil-tool interaction models

2.2. Soil parameters

2.3. Crop parameters

2.4. Development of root-crop harvesting systems

2.5. Economics of mechanical harvesting

2,1. Soil - tool interaction models

Soil working tools cause the soil to fail as it moves through it. The models of soil failure are extremely complicated in agricultural soils and vary with soil and tool parameters. The dynamic soil reactions are of prime importance from the point of view of digging tool design. Hardy (1938) found out that in case of tools designed to cut plant roots, the blades are to be swept back at an angle between 20 and 50 deg to increase cutting effectiveness.

Chase (1942) while analyzing lift angle of tiller blades, observed that a low lift angle (rake angle) of 16 deg accelerated soil cutting and higher lift angles accentuated the upheaval of soil around the tool and that the soil shattering was satisfactory at higher lift angle of 35 deg for dry and brittle soils.

Kawamura (1952) reported that minimum draft occurred at a lift angle of 25 deg for shallow tillage tools. Payne (1956) suggested that at 20 deg lift angle, the draft for a 10 cm wide chisel was minimum.

Payne and Tanner (1959) carried out experiments on rake angle of inclined tools for their performance. It was determined that the pattern of soil failure front has a crescent shape on soil surface with failure starting from the cutting edge of the tool and expanding into a crescent. It was reported that the length of soil crescent measured from cutting edge was shorter at acute rake angles and that a change in rake angle by 1 deg caused 2/3 deg change in the resultant's direction and attributed it to tangential stress caused by soil-metal friction.

Kaburaki and Kisu (1959) observed that an increase in approach angle decreased draft until an angle of 40 deg. Osman (1964) studied the behaviour of wider cutting blades and observed that the draft was minimum at a lift angle of 20 deg. Hettiaratchi *et al* (1966) developed a two dimensional model for soil failure in front of a wider tool cutting the soil. Gill and Vanden Berg (1967) also reported that draft force was minimum at 20 deg lift angle for inclined tools which are operating at shallow depth. Luth and Wismer (1971) defined the blades upto a width of 254 mm as narrow blades and stated that the draft was related to the square of velocity. Hettiaratchi and Reece (1974), Godwin and Spoor (1977), Mckyes and Ali (1977), and Perumpral *et al* (1983) applied the technique to narrow tillage tools and it was optimized to a share lift angle of 20 deg for minimum draft. Mckyes and Ali (1977) determined a failure model consisting of a straight rupture plane starting from the cutting edge to the soil surface and it was concluded that the draft force was minimum at a lift angle of 20 deg. Godwin and Spoor (1977) and Grisso *et al* (1980) indicated that the performance of a soil working tool depended on its shape, orientation during movement and initial soil conditions. It was concluded that the draft force of a soil working tool is directly proportional to the tool width and increases exponentially with operating width.

Sizov and Milyutkin (1978) analytically studied the interaction between the blade of a hoe inclined at less than 25 deg and the weeds in particular to the sliding of the weed along the blade edge. The conditions required for sliding and the effect on weed and blade hoe were examined. It was concluded that at rake angles of less than 20 deg the sliding was better.

Harrison (1982) tested inclined blades at various rake angles in a glass sided box and measured the forces on the blades. It was observed that the draft had direct relationship with rake angle and depth. The draft increased at a lesser rate up to 20 deg rake angle and increased drastically beyond 20 deg rake angle.

Stafford and Tanner (1983) reported that the draft force on tools increased with tool speed. Kepner *et al* (1987) stated that the penetration of tillage tool is determined by its suction and this suction had an important relationship with the approach angle of the tool shank and could be altered by changing inclination of the shank through the hitch point.

Harrison (1990) developed a soil surface profilemeter to measure soil elevations above a tool surface during tillage. It was found that the depth of soil flow varied as soil flew across a plane tool inclined at angle of 30 or 45 deg to horizontal.

Yumnam Jekendra and Pratap Singh (1991) recommended the optimum values of rake angle between 10 and 30 deg for minimum energy requirement for other root crops, since the blade rake angle affects the energy consumption in cutting and digging the soil.

Hanna *et al* (1993) concluded that soil shift or lateral soil movement and ridge height were affected by both tool operating speed of 5 to 9 kmph and sweep rake angle of 13.5 to 44 deg. The faster speeds and steeper rake angles created larger ridges. Soil loosing showed a quadratic relation with the speed.

Kushwaha *et al* (1993) in their review of all analytical and numerical models to predict soil forces acting on the tillage tools suggested the finite element analysis method as a flexible and accurate one to simulate the tillage operation. It was also suggested that these models could be applied for blades also by approximating the soil failures.

Ros *et al* (1995) developed a new approach to tool design based on mathematical description of tool surface with computer program. They suggested a rake angle of 20 deg for cultivator sweep and 60 deg for bulldozer blade.

Duraisamy (1997) reported that the rake angle, approach angle of tool, and the tool shape significantly affected the draft and the harvesting efficiency for mechanical harvesting of groundnut,

2.2. Soil parameters

The importance of soil moisture for digging of soil by the tool is discussed in this section.

Fountaine (1954) concluded that the soil tool adhesion mostly varies considerably with soil moisture and that the largest contribution to draft is from the cohesion of the soil, which is influenced by soil moisture.

Chesson *et al* (1978) found that the carrier for the topper under cutter was overloaded and this resulted in sinkage plus excess draft particularly in sandy soil conditions. It was concluded that a larger capacity carrier and reduced loading should eliminate these problems. Another approach would be to belly mount the toppers on a high clearance tractor to provide more stability and better control of the topping operation. They recommended an automotive sensing and height control on future topper designs.

Durant *et al* (1981) developed soil bin test facility for tillage tool interaction and to estimate the normal pressure on the soil rupture surfaces and soil interface.

Jan *et al* (1991) concluded that power requirements of tillage implements play an important role in the design of tillage implements. Studies were conducted on selected implements such as rear mounted three bottom mould board plough, rear mounted three bottom disc plough, and rear mounted tandem disc harrow in clay loam soil at moisture content of about 16 per cent at a depth of 150 mm. The power requirements of implements under study were calculated and suggested suitable plough for that soil.

Wulfsohn *et al* (1996) discussed agricultural shear strength based models and concluded that soil-water characteristics determine the soil behaviour. It was predicted that for a tool width-depth ratio of 5, operating at 150 mm depth and 40 deg rake angle, the draft of the tool increased to

2 kN up to 15 per cent moisture content, whereas the draft increased to 5.5 kN when the soil moisture was reduced to 13 per cent.

Duraisamy (1997) found that decrease in soil moisture increased the draft requirement for mechanical harvesting of groundnut and suggested 13.5 per cent as optimum soil moisture for loamy sand and sandy loam soils to harvest groundnut.

2,3. Crop parameters

Sastri (1950) indicated that turmeric crop is planted in ridges 22 to 25 cm high and 30 to 45 cm broad, the planting distance varying from 15 to 22.5 cm and at a depth of 7.5 cm and flowering of turmeric occurs in 5 months and the rhizomes then begin to form. The crop is ready for digging out at about 9 months when the lower leaves turns yellow. The leafy top is cut off and the roots are removed by digging out and all adhering earth is shaken or nibbed off, the rhizomes are then well washed with water. The yields of fresh raw turmeric vary from 16.8 to 22.4 t/ha for irrigated crop and 6.72 to 8.96 t/ha under rainfed condition.

Burkill (1966) observed that the primary tuber at the base of axial stem of turmeric croj) is ellipsoidal, about 5 cm by 2.5 cm bearing many rhizomes, 5-8 cm long, 1.) cm thick, straight or little curved, with secondary branches in two rows, whicl may have tertiary branches, the whole forming a dense clump.

Rama Rio *et al* (1975) described that in harvesting turmeric crop, the rhizomes are net to be bruised or damaged and that the whole clump is to be lifted out. It was shown that the colour content increased during the first two months of harvesting season and subsequently tended to decrease. It was also found that the pigment content of turmeric increased to a peak and then declined during the maturation of the rhizome, and that the optimum time for harvesting can iiffer according to *A* particular cultivar and the location of cultivation.

Mathai (1976) reported that cureumin content varied depending on stage of harvest and varieties. Govindarajan (1980) indicated that in turmeric, the vegetative growth characteristics such as number of tillers, height of plant, number and size of leaves etc. were found associated with yield but were variable. It was also described the rhizome of turmeric as having multilayered, thin walled cells in radial rows forming the cork tissue.

The curing percentage is largely varietal character ranging from 16 to 21 per cent. Cureumin (CnHhoOe) is the principal colouring constituent which imparts characteristic yellow colour to turmeric (Narayanan *et al* 1982). Sivaraman (1992) identified number of tillers, number of mother rhizomes, number of primary and secondary fingers per plant as major yield attributes of turmeric. The limited information suggests that the most important single influence on the quality of dried turmeric is the intrinsic characteristics of the cultivars grown, and that the second most important factor is probably the stage of maturity of the rhizome at harvest.

2.4. Development of root crop harvesting systems

Root crops like turmeric, potato, groundnut, sweet potato, sugar beet, and cassava require digging of the soil along with the crop for harvesting the produce. Different harvesting systems have been developed for different root crops which are discussed in this section.

Johnson (1974) concluded that the vibrating blade equipped with a potatoes harvester was found to have lower draft in the tests than other commercial harvesters. However the lower draft was not apparent when digging potatoes. It was recommended that future design was needed on the blade shape and its mounting, to reduce the draft while digging and eliminate the high percentage of cut tubers.

Peterson *et al* (1975) studied the various problems of potato damage at harvest and found out that at higher field speeds of operation of the harvesting machines, the bruise damage of the potato decreased over three years of trials. The field losses from potato combines were observed less than 2 per cent and could be controlled by the operator.

Punjab Agricultural University, India developed animal drawn single row potato digger during 1973-75 (Anon., 1975). It is suitable for digging and exposing tubers from one row. It is provided with a V-shaped blade with round bars at the rear. These rods help in separation of soil from potato tubers.

Pratap Singh and Pandey (1981) evaluated the soil separation by a potato digger elevator equipped with oscillating and non-oscillating blades and found that the soil separation improved speed either at a slow forward speed or at higher conveyor speed. The power requirement for soil separation was lower for an oscillating blade, but the total power requirement was higher for oscillating blade.

Allison and Davila (1982) developed a simple method of mechanical digging of most tropical root crops. Heavy-duty equipment and large tractors were generally required to harvest tropical root crops and their removal. A heavy duty sub-soiler with a weeder knife attachment had to be passed beneath the soil near the root zone to loosen the soil. Subsequently, a second operation is needed with heavy-duty slatted mould broad plough to bring the root crop to the soil surface where it can be picked up by hand or a mechanical loader.

Misener and Me Millan (1982) developed a single hill digger capable of digging hills of potatoes spaced 750 mm apart and depositing them on the soil without mixing tubers from adjacent hills. The use of the digger improved the effectiveness and efficiency of the harvest crew. The potatoes are cleanly separated from the soil and individual plants remain well separated which makes it easier for the selectors to do their job.

Birsa Agricultural University, Ranchi, India (Anon., 1983), has developed an animal drawn potato digger. It saves 40 per cent labour and operating time and 18 per cent cost of operation compared to conventional method of digging with spade. It also results in reduction of 11.3 per cent losses compared to conventional method of digging with spade.

Misener *et al* (1984) designed a two row potato digger to dig, lift, and load the potatoes. The digger blade shape was 250x130x60 mm high carbon steel which oscillated about the centre point. Ganshyam Das and Avinash Agarwal (1985) developed concave shaped share plate for potato digger attachment to country plough.

Razmyslovich and Skvarski (1985) developed two rotors which were mounted behind the digging shares and in front of a slatted elevator to separate smaller foreign matter. The field tests were conducted on 3 types of soil with moisture content of 26-27 per cent and at three forward speeds (0.5, 1.5 and 2.0 m/s). The efficiency of separation was improved with increase in the forward speed. The separation was optimum and tuber damage was within acceptable limits. The machine was more efficient on heavier soils.

Misener (1985) developed and evaluated a small-scale three-point hitch tractor mounted potato digger. This digger was designed and constructed to have minimum injury to the potatoes. It was equipped with a hydraulic drive and was found to be very flexible and suitable for variable harvesting conditions.

Hyde and Thorntor (1985) conducted field experiments to compare the draft required for rotary disk blade system with that for a conventional, fixed blade potato harvester in sandy and silt loam soils. Studies were conducted to evaluate blade performance and tuber damage for the rotary blade system and the depth/draught relationship for the fixed blade. The field tests showed that in silt soil 0.91 m diameter of rotary disk blades required 76 per cent less draft than the fixed blade. The draft required for fixed blade increased significantly with blade depth in deep digging with proper adjustment of attack angle and lateral tilt angle. Tuber damage caused by the rotary blades ranged from 1 to 3 per cent.

Sharma and Verma (1986 and 1986b) designed an improved prototype of tractor drawn oscillating potato digger and main emphasis was given for vibration control in the design. The blade was of the size 510x260x8 mm and for a single row operation the draft required was 80 to 105 kg. As the forward speed increased from 0.35 to 0.75 m/s, the damage to tubers increased from 0.3 to 0.7 per cent and the undug tubers increased from 6.6 to 14.4 percent.

Sharma and Verma (1986) developed oscillatory potato digger and estimated that the harvesting of root/tuber crops required about 600 man-h/ha for manual digging as against an animal drawn plough which reduced the labour to about 300 man-h/ha and a tractor operated digger required 80-90 man-h/ha. The digging units consist of U-shaped or straight blade and lifter rods are spaced to allow the clods and residual material to drop while operating the implement. The plant along with roots/tubers is collected manually.

Mcleod *et al* (1989) utilised the concept of elevating potatoes and adhering soil from digging shares to design improved potato harvesters. Misener and McLeod (1989) developed a mechanism which consisted of a combination of disc shaped clod rollers and cylindrical brushes. The prototype separator effectively sieved all the loose soil from the potatoes, 60 per cent of the stones and 47 per cent of the clods with reducing power consumption.

Gupta *et al* (1989) evaluated the performance of Bakhar blade with respect to tools of different geometry such as straight, convex, concave, triangular and V-shaped in a lateritic sandy loam soil under uniform soil conditions. On comparing the overall performance of different tools at 25 mm and 75 mm working depths, the convex tool recorded a minimum specified draft of 2 N/cm 9 and 1.76 N/cm 7 at the rake angle of 55 deg.

Varshney *et al* (1989) developed and evaluated a functional prototype of potato digger operated by a pair of bullocks and evaluated on the farmer’s field. As per the performance data reported, the potato digger developed at the Department of Rural Engineering was better than indigenous plough in all respects. The potato digger could perform well in various soil moisture conditions.

Kang and Halderson (1991) also designed a two row vibrating blade potato digger and it was found that increased travel speed, decreased shatter bruise and black spot of potatoes due to more retention of soil on blade; that draft force decreased as vibrational frequency increased and travel speed decreased. The draft varied from 7.9 to 12.2 kN and the average draft/unit area of furrow slice was 3.3 to 4.2 N/cm^2 for 1.7 to 3.3 krnph forward speed.

Divis and Sterba (1997) found out that mechanical damage to potato tubers was higher in unfertilized crops and phosphorous was found to provide a favourable effect of reducing mechanical damage to the tubers.

Manjit Singh (1999) at Central Potato Research Station, Jolandhar, Punjab, India developed tractor drawn trailed type two-row potato digger windrower. It is essentially a double chain elevator digger with additional dicone rollers, trash separating system and an adjustable V-shaped scraper. During the actual field operation, the rollers were pressed upon two adjacent ridges to make them loose and friable. These are then lifted up by digging blades and passed on to the vibrating primary and secondary elevator conveyors. While bulk of the soil gets shifted through those conveyors the tubers along with trash fall upon an inclined belt conveyor. The trash gets separated and the tubers roll down to get windrowed in a shallow channel made by the V-scraper during evaluation on the field condition. The effective field capacity of the prototype was 1.6 ha/day. The digging and windrowing efficiencies were 98 and 90 per cent respectively. Bruising of tuber was 1.5 per cent and the labour requirement for picking of dug tubers was approximately 50 per cent less compared to those dug by an elevator digger.

Sunil Gulati and Manjit Sing (1999) developed an oscillating type potato digger incorporating the horizontal oscillating motion mechanism. The potato digger was found to have an effective field capacity of 1.75 ha/day and a tuber exposure 85-90 per cent depending upon soil and field conditions. The optimum speed of operation of digger was 2.0 -3.0 kmph.

A single-row ridge-type sliding potato digger attachment to power tiller was developed by Kathirvel and Manian (2001). The unit was evaluated for its performance and compared with commercially available oscillating type diggers and manual digging.

Dijkhuis and Visser (2002) developed a light weight potato lifter in the Netherlands based on a round ridge cutter and a helix-shaped sorter. The results showed that the damage to tubers was low, cleaning was very easy and soil compaction was minimal.

Potato digging by manual method is a slow process, labour intensive and involves lot of drudgery. As a result, many times digging gets delayed and fields become dry and hard. Keeping these problems in view, Sukhvinder Singh (2006) developed two-row tractor operated potato ridge loosener at Central Potato Research Station, Modipuram, Meerut, Uttar Pradesh, India. It has three point hitch system and a main rectangular frame made up of 50x50x6 mm square pipes. At both the ends mild steel frame was provided with two 600 mm long vertical columns made up of 75x10 mm flat. Bottoms of these columns were joined with 1100 mm long thick blade. This ridge loosener was extensively tested with tractor. When the blade moves through the ridge 50-70 mm below the potato tuber zone, soil is completely loosened with minor displacement of tubers from their original position. The field capacity of the implement was 0.4-0.6 ha/h and 35 per cent less labour was required as compared to traditional manual digging.

2.4.2. Groundnut

Stokes and Reed (1950) reported that the purpose of shaking equipment in a groundnut combine was to lift the crop out of the ground, shake off the soil and place them in the windrow.

Punjab Agricultural University, India evaluated a tractor drawn groundnut digger which had a 1220 mm long digger blade to uproot the crop (Anon., 1974). The machine with 1220 mm straight long harvester blade allowed the crop to be uprooted. It also facilitated easy removal of the harvested crop and its collection by manual labour without any loss of groundnut in the field.

Narayana Rao (1974) reported the progress of groundnut harvesting mechanisation in Andhra Pradesh, India. The bullock drawn harvesting crescent blade is 457 mm long and is made of 100x6 mm flat iron.

The lifting and lowering mechanism of the blade facilitates depth adjustment. Two disc coulters were provided to cut the vines on either side of the blade and a tail wheel provided with a swivel mounting facilitated turning of the implement at the head-land. The field capacity of the implement was 0.6 ha/day with a field efficiency of about 80 per cent.

Ruiz *et al* (1975) conducted mechanical tests to ascertain the suitability of groundnut for mechanical harvesting and it was found that the force required to detach pods in the soil during mechanical harvesting depended to some extent on gynophores length. The moisture content of groundnut pods influenced the losses during mechanical harvesting.

Vedak and Young (1976) constructed simulation models for comparison of conventional windrow, hay-topping and a once-over methods of groundnut harvesting. These models could be used effectively to observe the influence of various parameters on the groundnut harvesting process. White and Roy (1982) found out that once-over harvesters for groundnuts gave higher yield than digging and combining.

Mizrack *et al* (1983) studied about a groundnut salvage machine that worked in sandy loam and clay loam soils. The upper layer of the soil containing the groundnut that remains after harvesting was elevated by a pick up digger that shook most of the loose soil. Thomas *et al* (1983) measured the groundnut pod peg strength with Instron instrument which influenced the proportion of groundnut pods harvested and directly correlated the peg anatomy characteristics with peg detachment forces.

Savani *et al* (1983) conducted experiments with different groundnut diggers and concluded that the diggers reported by Ali *et al* (1979) performed better than harrows and discussed about a few designs of groundnut diggers developed by the research institutes in India to reduce the draft and clogging plants. These diggers have essential variations of blade harrow having different sizes and curvatures.

Yang Ren Hwang (1983) developed a small scale self propelled one way operation groundnut harvester in which the peanut vines with pods were pulled up from soil by hydraulic control unit. Mizrach *et al* (1983) developed and tested a groundnut digger with picker conveyor suitable for sandy loam and clay loam soils. The upper layer of the soil containing groundnuts that remain after harvesting was elevated by pick-up digger that shakes most of the loose soil. A shaking rod conveyor system efficiently separates the clods. The results revealed that the machine can efficiently recover groundnuts from a large percentage of clods at a high field efficiency of 75 per cent.

Ahamed (1984) opined that the approach adopted in development of machines should consider design that are complimentary with on-farm resources and are capable of being produced, utilised and maintained using local skills.

Ameobi *et al* (1984) developed an experimental plot groundnut lifter for small scale farming. The machine consisted of a simple tool frame formed of hollow square sections. The 'V' shaped blade of 540 mm length with round bars at the rear was attached to rear portion of the frame. The blades were tested at different lift angles. Field tests yielded the optimum lift angle of about 20 deg. Soil pulverization was more pronounced for higher lift angles.

Havard (1985) classified the groundnut harvesting equipments into two types; one is digger shaker windrower with oblique blade with extension fingers and the other is the digger - vibrator with a straight lifting blade mounted on two legs and a tined vibrating table.

Awadhawal and Takenage (1988) developed bullock drawn and tractor drawn diggers for harvesting bunch type groundnut in dry hard soils. It consisted of two shares inclined at 120 deg to each other and chisels points for increased penetration into hard pan. It was found that the bullock drawn single digger unit covered 400 mm strip of the crop in single pass whereas the tractor drawn two bottom digger unit covered lm wide strip.

Maraviya *et al* (1988) determined that the draft requirement was 95.25 kgf in the case of bullock drawn groundnut digger. Liang *et al* (1989) conducted study on the once over groundnut harvester. It could dig, lift, pick, and separate step by step during single pass.

Bilanski *et al* (1989) reported that single bottom tractor mounted machine capable of harvesting the groundnut crops of high moisture content ranging from 45 to 60 per cent (w.b.). The effective harvesting capacity of the machine was found to be 0.15 ha/h. Garg *et al* (1990) compared the performance of groundnut digger shaker and groundnut digger with corrugated roller and found that the groundnut digger windrower required only half the man power of the digger with corrugated roller.

Dawelbeit (1991b) reported that for vibratory type groundnut diggers, the draft was significantly affected by soil type, tractor speed and amplitude of vibration and the vibrations did not affect crop losses. Gupta and Parmar (1991) developed and evaluated an improved bullock drawn groundnut harvester. The bullock drawn harvesting ‘V’ shaped blade is 450 mm long and is made of 100x6 mm flat iron. The lifting and lowering mechanism of the blade facilitated depth adjustment up to 150 mm. It digs deeper in the soil and leaving a minimum number of pods in the soil and reducing harvesting losses.

Dawelbeit (1992) observed that the harvesting losses were largely contributed by pre-combining losses. Dawelbeit (1991a and 1993) studied the effect of mechanical shaking of groundnut combining losses in heavy clay soil and concluded that extra shaking reduced the combining losses by decreasing pre-combine and header losses and that the heavy clay particles adhering to groundnut pods created problems in combining.

Parmar *et al* (1994) observed a computer simulating model to calculate operation hours of each unit of the machine to determine cost economics and ' developed an equation for calculating the digging speed.

Awadhawal *et al* (1995) developed a digger for digging groundnuts of bunch variety in dry and hard soil which consisted of two shares inclined at 120 deg to each other and chisel points for increased penetration into hard pan. A single digger unit attached to a tool bar is pulled by a pair of bullocks. The width of coverage of the digger was 600 mm. It was reported that the harvesting losses was less than 5 per cent and the average field capacity of the chisel digger was 0.7 ha/day.

$$S_d = (P_t - Pd_{PTO} R_d)\ Teff / (D_d R_d + W_d C_r) \qquad \ldots (2.1)$$

where,

S_d = Digging speed, kmph

P_t = Tractor power available, kW

Pd_{PTO} = PTO Power requirement of digger, kW/row

R_d = Number of rows

Teff = PTO to draw bar power transfer efficiency, fraction

D_d = Draft requirement of digger, N/row

W_d = Digger weight, N

C_r = Coefficient of rolling resistance

Awadhwal *et al* (1995) designed and developed a chisel digger for harvesting Virginia bunch type groundnut crop. The digger bottom had two shares inclined at 120 deg to each other and contained chisel parts. The penetration achieved was better than blade type diggers. Better results were achieved at the rake angle of 17 deg.

Duraisamy (1997) investigated a groundnut crop picker conveyor attached to a tractor drawn digger blade. Three typical tools of geometry *viz.*, straight tool, inverted-'V' and crescent at different rake angles from 5 to 20 deg and approach angles from 0 to 15 deg were evaluated. The width of the harvester was 1800 mm, which was well within the draft available from a 26.1 kW tractor. The draft varied from 236 to 250 kg in sandy loam to loamy sand soils.

Dash *et al* (1998) evaluated four types of bullock drawn groundnut diggers namely two - row ridging type, ridging type with semi circular blade, V-type blade and ridger type. Effective field capacity and digging efficiency were high in the case of V-type blade and ridger type blade respectively. It was concluded that the maximum field capacity of 0.057 ha/h and digging efficiency of 92 per cent was found in two row ridging type blade.

Gadir Omar and Desa (2001) evaluated the performance of tractor drawn peanut digger blades *viz.,* flat type, curved type, 'V'-shaped type and double discs. The results showed that the 'V' shaped type had lower average draft force for increasing digging depths of both inclined angles of 0 and 40 deg compared to other types. It was concluded that the design of 'V' shaped digger was simpler and was recommended it for peanut harvesting machine.

Tiwari and Jethra (2001) developed two row groundnut digger blade for small tractor which was tested and compared with traditional blades. The newly developed groundnut digger straight blade in the size of 750x250x10 mm was found to be the most suitable which gave maximum field capacity of 0.126 ha/h, field efficiency of 77.80 per cent, and harvesting efficiency of 94 per cent.

Verma and Garg (2002) developed groundnut harvester which is operated by a tractor of 26.1 kW or higher. The power take off (PTO) through a telescoping shaft supplies power to the gearbox of the machine consists of a digging blade of 1200 mm length. The capacity of the machine varied from 2.0 to 2.5 ha/day.

Suryawanshi (2003) designed and developed a power tiller operated groundnut digger and evaluated the performance of tools with respect to their geometry such as straight, inverted 'V' and crescent shape. The maximum harvesting efficiency of 99.99 per cent was achieved at the combination of 15 deg rake angle, 15.5 per cent (d.b.) soil moisture level and straight shaped tool of width of 500 mm.

2.4,3. Onion

Lorenzen (1950) developed an onion harvester with a view to cut the root and to lift the onions. The digging unit of the machine consisted of a single narrow blade, wedge shaped in cross section, mounted on a single standard from the furrow side of the bed and slanted rearward at an angle of about 20 deg to aid shedding of weed roots. In heavy soils, a steep angle of 18 deg was maintained to break up the ground and lift the onions into the belts. In light soils, a shallow setting of 6 deg disturbed minimum of soil and gave best performance, with field capacity of 0.80 ha/h at a forward speed of 1.6 kmph.

Carson and Williams (1969) developed an experimental onion topper to pick up two or more rows of onions to elevate them with a topping mechanism. A rotary blade of 450 mm diameter was used to remove the tops. The rotary blades were positioned very close to the tined wheel so that tops would be cut before the tined wheel reached the top. Four gauge wheels were used to maintain uniform cutting height. These wheels were positioned between the rows on top of the onion bed. The field tests indicated that the lifters operated satisfactorily making an angle of 25 deg with the direction of travel and inclined away from the onion row at an angle of 5 deg with the vertical. Topping knives were set 100 mm above ground. Field tests also revealed that the topper performed better in the afternoon than during early morning hours.

Lepori and Hobgood (1970) found that condition of tops was found to be the most important factor affecting harvesting efficiency of onion. The harvesting efficiency generally exceeded 90 per cent where tops were in good condition. The guide of 50 per cent tops down presently used by growers appears to be adequate for indicating maturity for mechanical effect with the belt lifting principle.

Peterson *et al* (1975) reported that as the field speeds increased bruise damage decreased over three years of trials. The field losses from potato combines were observed less than 2 per cent and can be controlled by the operator.

Harold Gene and Medlock(1976) developed a green onion harvester which included a plurality of mechanisms for grasping the foliage, severing the roots, withdrawing the green onions from the soil, sorting out undersized green onions, removing the lower leaves, and depositing the green onions in a collection bin.

Droll *el al* (1976) evaluated that the moisture content of the onions, the weight and quantity harvested, showed no significant differences due to the method or timing of undercutting. The maximum moisture content variation observed was from 90.3-91.7 per cent; the method of undercutting was shallow with the rod weeder.

Johnson *et al* (1977) developed a harvesting unit which comprised of tractor mounted rotary topping heads and weed lifting bar operating in conjunction with a mobile or stationary bulb trimming device in the form of series of parallel rods spaced 37.5 mm apart over which the onions were moved by an overhead conveyor equipped with rubber fingers; hydraulically operated rotary blade clipped off the roots projecting between the rods.

Chesson *et al* (1978) developed two toppers (sickle bar topper and rotary topper) and a trimmer for fresh market onions. Machine harvest produced 5 percent mechanical damage.

Tomita *et al* (1978) developed a self-propelled mechanical onion **digger** powered by a 5.4 kW engine, with a working width of 1.25 m. The digger was operated at a speed of 0.18 to 0.45 m/s. The field trials indicated that at 0.45 m/s, the machine lifted 83 per cent of the crop without damage at the forward speed of 0.45 m/s. The field capacity was0.16 ha/h.

Maw and Smittle (1986) studied the undercutting of onions. The dry bulbs of the Granese type were undercut to facilitate lifting during harvest operations using both oscillating and rotating bar under cutters. The analysis of cleanliness, damage and disturbance to bulbs revealed that operating the rotobar at the speed of 540 rpm to a depth of 25 mm below the soil surface and at a forward speed of 6.4 kmph gave the best results.

Medvedav *et al* (1989) reported a method of mechanical harvesting with pre drying of green leaves using magnesium chlorate spray (20 kg/ha delivered in 400 1 solution). The plants were sprayed with the chemical 6-9 days prior to harvest; desiccated foliage was wetted with clean water 15-20 min before lifting to reduce brittleness and thereby to reduce the harvesting losses. The improved separator of mechanical harvester was operated on friction principle. The lifted onion were transported by a series of bar and grill conveyors to eliminate foreign matter. In laboratory tests, relationship between crop quality and losses, dimensions and geographical arrangement of the conveyors were assessed. In field test under a range of climatic and soil conditions, the crop losses caused by machines ranged from 2.7 to 9.3 per cent.

Ulger *et al* (1993) developed the onion digger machine, which has a frame, digging blades, a separation system, an adjustment system for the digging depth and a carrier system that is activated by the tractor pto. The efficiency of harvesting machine was higher than manual harvesting but harvesting loss was slightly higher compared to manual harvesting.

Jadhav *et al* (1995) fabricated a low cost self-propelled onion digger windrower powered by a 3.73 kW diesel engine mounted on the wheeled frame along with a gear box. The digging unit consisted of sweeps and depth control was achieved by a castor wheel in front of the digging unit. The damage to the bulbs was 2.6 to 3.5 per cent and digging efficiency was 89.7 to 93.2 per cent.

Maw *et al* (1998) designed and evaluated mechanical haivesting of sweet onions. The key features included a lifting head for each row comprising of guides for lifting the tops, gathering wheels, under cutter, lifting belts, depth gauge wheels, shaker soil topper to cut tops from the bulb; a conveyor to move onions from lifting-head to the container and a conveyor to dispose the tops. In addition to the driver, a machine operator was seated in such a position as to have a clear visibility of the lifting head during the harvesting operation.

A maximum ground speed of 2.4 kmph, a lifting-belt speed equal to 125 percent of ground speed, an onion bulb root length of 10 to 40 mm were chosen for the appropriate harvesting operation,

Sandeep Mann and Sudama Aggarwal (1998) successfully tested the tractor drawn potato digger with an 'A' shaped share for harvesting onion. The digging efficiency was 96 per cent.

2.4.4. Cassava

Odigboh and Ahmed (1982) developed a prototype cassava harvester which had a separately powered rotary knife mounted in front of tractor to cut the stems and cassava root lifter mounted behind the tractor. The root lifter was a reciprocating hoes (V-shaped) mounted at the rear of the tractor. The rake angle was 20 deg to achieve maximum penetration and scouring. The breakage to the cassava was 1.5 to 2.7 per cent in ridge type and 9.7 to 10.3 per cent in flat type with undug being 1.8 to 2.5 and 15.1 to 16.6 percent, respectively.

Carib Agro Industries Ltd, Barbados developed cassava digger and sweet potato and turmeric lifter (Anon., 1990). The machines undercut the crop deeply with strong shares and loosened the soil with metal fingers which reciprocated deeply beneath the crop. The fingers moved the soil backward so that the root floated out of the bed. Hand labour could pull the tubes from the soil easily. The turmeric digger had a wider blade.

Gupta *et al* (1999) developed a cassava root harvester at Asian Institute of Technology, Bangkok, which is a wedge-shaped vibrating plough consisting of a triangular share and a slot type plane bottom inclined at 25-30 deg rake angle. It is attached to the main frame by two leaf spring beams. The harvester is rear mounted and can harvest 100 per cent roots. It requires 16 kW draft power at speed of 6.1 kmph at 37 cm depth in sandy loam soil at 18.6 per cent moisture content (d.b.). The maximum field capacity was 0.64 ha/h.

A technical analysis of the state of the art in mechanisation of cassava harvester is currently available in the world market and that the available cassava harvesting aids can only do a good job of loosening the soils around the cassava root bunches. Odiboh (2002) studied the concept based on the existing harvesting aids and designed to remove identified gaps in the technology of mechanised cassava harvesting, involving the lifting of the loosened cassava root bunches out of the soil and loading them into a truck on trailer. The proposed concept comprises a cassava harvesting aid, an uprooter, lifter system, a collector/channeling chute and an elevator/loader system.

2.4.5. Sweet **potato**

Michael Obrien and Scheurman (1969) modified the tractor drawn potato digger for harvesting sweet potatoes. The digging operation was accomplished with a wide, lifting blade mounted in front of a lifting conveyor. The back of the digger blade slopped back and up so that it discharged the roots and all soil surrounding them on to the rod lifting belt. To avoid bruising and damage of sweet potatoes while being transferred at the rear of the blade, a rubber roller was installed across the width of the conveyor inside the rods.

James Hammerle (1970) discussed about the various parameters to be considered for harvesting sweet potato and developed an experimental sweet potato combine which had a digger blade used for potato diggers, elevator, stem impactor and size grader. The stem impactor struck the stem root potato system causing sweet potatoes to drop into the conveyor.

Abrams *et al* (1978) evaluated the mechanical sweet potato harvesting system in comparison with conventional hand harvest for bulk harvesting. The mechanical harvester had an inclined digging blade engaging the furrow section, agitated rod type conveyor and over head conveyor and snap roll mechanism. Less damage and greater recovery of sweet potato tubers by mechanical harvesting was reported.

2.4.6. **Sugar beet**

Urschel (1946) reported that the sugar beet combine harvester pulled along the row of beets, with a one-pointed lifting plough entering about 300 mm into the soil below the beets.

Guelle (1946) analysed a Me Cormic-Deere harvester which performed topping, lifting, cleaning, loading, and transporting the beets to the edge of the field in one continuous operation. The beets were lifted from the ground by two lifter blades.

Prochazka (1967) determined the force and power relationship for harvesting sugar beet with a few types of lifting tools. It was observed that over the forward speed of 1.0-2.0 m/s, the draft increased with shares having a negative cut angle. The draft increased with working depth.

Srivastava and Yadav (1978) studied about three row tractor drawn sugar beet diggers and used sweeps as lifting shovels at a spacing of 150 to 200 mm. The harvesting efficiency was 98.8 per cent and the damages were about 1 percent.

Thakur *et al* (1980) conducted experiment on tractor drawn sugar beet digger. Three types of shovel namely, duch pot shovel, double pointed shovel, and hoe shovels were tested as digging tools and the double pointed shovel was found to perform better at a depth of 12 to 14 mm at a speed of 3.1 kmph.

Now-a-days, the trend in sugar beet harvesting is towards the use of machines with a high work rate to harvest large areas. In many cases, the sugar beet harvesters are designed to retain the root for longer time inside the machine and by fitting more efficient cleaning mechanisms. Bentini *et al* (2002) developed an electronic beat with a 4905 m/s^2 tri-axial accelerator at the University of Bologna, Italy. This device was used in a field trial for measuring and recording impacts in terms of peak acceleration, duration, and velocity change during impact. The device was placed into the soil in place of a real beet and then harvested by a six-row self propelled harvester which was tested at four different forward speeds. Assessment of the level of damage on the harvested sugar beets was also carried out. The results of the study showed that the harvester forward speed of 6 kmph caused the fewest tap root beaks and bruises.

2.4.7. Turmeric

Subramanian *et al* (1992) developed a power tiller operated turmeric digger. The attachment to power tiller was made by connecting the hitch bracket on the end of the longitudinal beam of the frame to the hitch plate of the power tiller by means of a pin. The bottom consisted of a share, blade, and share clamps. The machine was designed to harvest two rows of turmeric, which resulted in saving of time.

Murugesan and Tajuddin (1995) developed a turmeric digger with two digger blades of size 825x150x10 mm joined together for proper penetration and to reduce draft. The tubers were left in soil without inversion.

Mahatma Phule Kirishi Vishva Vidhyalaya (M.P.K.V), Rahuri, India developed (Anon., 2002) tractor mounted turmeric digger. The blade length was 60 cm and depth of digging was 18 - 20 cm. A set of lifting rods/ gathering rods at the rear of the blade lifts the harvested rhizomes to drop it backward but the draft requirement was reported higher.

2.5. **Economics of** mechanical **harvesting**

2.5.1. Groundnut

Garg *et al* (1990) evaluated the groundnut digger shaker windrower and groundnut digger with corrugated roller and the economics of operation was compared with manual harvesting. Total labour requirement in the case of digger windrower was 30 man-h/ha which was half of that of digger with corrugated roller while it was 150 man-h/ha for manual harvesting. The cost of harvesting was Rs. 246 to 262/ha for mechanical diggers as against as Rs. 375/ha for manual harvesting.

Dawelbeit (1991a) found out from his studies that the labour requirement for manual harvesting and fully mechanised harvesting was 411 and 19 man-h/ha respectively. Bindu and Kilgaur (1994) reported that the labour requirement for groundnut harvesting in Northern Nigeria could be reduced from 430 man-h/t by manual harvesting to 20 man-h/t by mechanical harvesting.

Duraisamy (1997) observed that the cost of operation of tractor drawn groundnut harvester was Rs. 600/ha as against Rs. 880/ha by manual harvesting, with a saving of 31.7 and 95.9 per cent in cost and time respectively. The break even point for the harvester was 17 ha/annum.

2.5.2. Cassava

Odigboh and Ahmed (1982) calculated that the tractor operated cassava harvester could effectively save 20 man-h for harvesting 0.16 ha of cassava field.

2.5.3. Onion

Williams and Franklin (1971) conducted experiment with mechanical onion harvesting equipment to develop a method of field topping of onions. It was reported that the topping cost could be reduced if onions were laid in windrows. An elevator chain conveyer was used to move the onion bulbs over the clod rollers.

Sandeep Mann and Sudama Agarwal (1998) found that the cost of harvesting of onion by tractor drawn digger was Rs. 716.50/ha as against Rs. 2154.30/ha by manual digging. The labour requirement for mechanical digging and manual digging were 21.24 and 269.2 man-h/ha respectively.

2.5.4. Turmeric

Senthilkumar *et al* (1991) worked out the cost of operation of the bullock drawn turmeric digger as Rs. 269/ha where as by manual digging, it was Rs. 900/ha making a saving of Rs. 631/ha. This works out to 70 per cent saving in the cost of operation. By harvesting with the implement we can save 16 times of operational cost compared to manual harvesting.

Subramanian *et al* (1992) reported that cost of operation of the power tiller operated turmeric digger was Rs. 189/ha where as it was Rs. 269 for bullock drawn digger and Rs. 900 for manual digging. Murugesan and Tajuddin (1995) worked out the cost of digging by tractor drawn turmeric digger to be Rs. 575/ha as against Rs. 300/ha by manual digging.

It is seen from the above review that though information on various aspects of mechanical harvesting of turmeric is meager, the available information on the related aspects in similar crops and soil-tool conditions suggest that the following parameters may have to be considered in the design of mechanical harvesting system for turmeric.

. Tool parameters: blade geometry and shape, conveyor/elevator parameters.

Operational parameters: forward speed, depth of cut

Soil parameters: soil type, soil moisture at harvest

Crop parameters: yield attributes of the crop *viz.,* number of tillers, number of fingers per plant, bulk density of rhizome at harvest, etc.