

**STUDIES ON DESIGN PARAMETERS FOR DEVELOPMENT OF
MECHANICAL HARVESTER FOR TURMERIC**

Thesis submitted in part fulfillment of the requirements for the award of degree of
Master of Engineering (Agriculture) in Farm Power and Machinery
to the Tamil Nadu Agricultural University, Coimbatore

By

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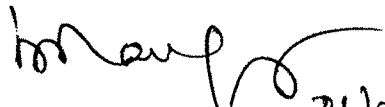
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This is to certify that the thesis entitled **STUDIES ON DESIGN PARAMETERS FOR DEVELOPMENT OF MECHANICAL HARVESTER FOR TURMERIC** submitted in part fulfillment of the requirements for the award of degree of **MASTER OF ENGINEERING (AGRICULTURE) in FARM POWER AND MACHINERY** to the Tamil Nadu Agricultural University, Coimbatore is a record of bona fide research work carried out by Mr. **S. JACOB KALAISELVAN ANNAMALAI** under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

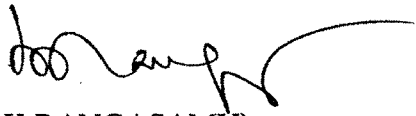
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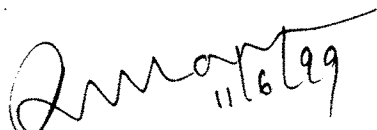

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EXTERNAL EXAMINER

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Fear of the Lord is the beginning of wisdom. Proverbs 9:10 (The Bible)

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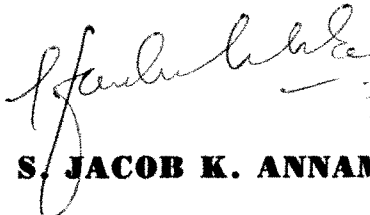
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S. JACOB K. ANNAMALAI

ABSTRACT

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STUDIES ON DESIGN PARAMETERS FOR DEVELOPMENT OF MECHANICAL HARVESTER FOR TURMERIC

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Harvesting of turmeric rhizome is one important aspect in turmeric cultivation which requires immediate attention for developing appropriate mechanical technology to reduce field losses and thus to increase productivity, to help in timely completion of the operation and to reduce the cost of operation. A study was undertaken to optimise the design parameters for developing a tractor drawn harvester for turmeric.

Important physical properties of two major turmeric soils namely, sandy loam and clay loam were determined. Relevant physical properties and the yield attributes of three varieties of turmeric, namely Erode, Salem and BSR-I were determined.

Dimensions and materials of critical components of the prototype mechanical harvester were designed and the prototype harvester was developed as an attachment to a 35 hp tractor with two digger blades harvesting alternating rows in the field.

Necessary provisions were made for adjusting the distance between blades to match the row spacing of the crop. Three shapes of the tool namely, straight, crescent and inverted V blades were selected as discrete levels of independent variable of tool geometry along with three levels of rake angle, 15, 20 and 25 deg; three levels of lift rod length 150, 250 and 350 mm and three levels of lift rod angle -5, 5 and 15 deg as independent variables of the tool, to evaluate the harvesting efficiency, draft and damage to the crop at the time of harvest.

The experiments were statistically designed and the data obtained were analysed and optimised to bring out the variable levels giving the best performance in terms of maximum harvesting efficiency, minimum damage within workable draft limit.

The results indicated that the mean soil moisture of sandy loam soil at the time of harvest was 14.69, 9.70 and 8.31 per cent (db) after irrigating the field 3, 7 and 12 days respectively prior to harvest while the corresponding values in clay loam soil were 23.97, 15.98 and 11.32 per cent (db) respectively. Maximum harvesting efficiency of 98.5 and 98.0 per cent were recorded after 7 days of irrigation prior to harvest in both types of soil at mean moisture level of 9.7 and 15.98 per cent respectively. The other soil physical parameters namely bulk density and cone index and crop parameters namely plant population, rhizome spread in the soil, rhizome weight and bulk density, no of fingers per hill and moisture content of rhizome were also determined.

The harvesting efficiency, draft and damage caused to the rhizome were significantly affected by the tool variables, tool geometry shape, rake angle, lift rod length and lift rod angle at 1 per cent level. The interaction and combined effects of the tool variables were also studied. The multiple linear regression analysis was done and the regression equations were obtained.

Comparing the best combination of tool parameters, the maximum harvesting efficiency of 97.6 per cent with minimum damage of 2.42 per cent and with a workable draft of 315.7 kg was obtained in the combination of crescent shaped blade of dimensions 450 x 250 mm, with 20 deg rake angle, 250 mm lift rod length and 5 deg lift rod angle at 2.5 kph forward speed and 200 mm depth of operation.

The field evaluation trails of the prototype harvester with optimised tool and operational parameters for the three varieties of turmeric in two types of soil were carried out. The effective field capacity was 0.191 to 0.197 ha/h; the harvesting efficiency was 97.20 to 97.66 per cent and the damage caused was 2.33 to 2.90 per cent. The cost economics study showed that the cost of harvesting per ha was Rs.5512 with prototype harvester and Rs.7480 for manual harvesting, with savings in cost of 26.3 per cent in mechanical harvesting. The break even point for the machine was 47 ha per annum and the pay back period was 3.62 years for the tractor drawn turmeric harvester.

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INTRODUCTION

CHAPTER I

INTRODUCTION

Modernisation of agriculture necessitates appropriate machinery for enhancing resource use efficiency and productivity in agriculture. Indian Agriculture has made tremendous progress in food production that, by 1970-71 our food grain production was doubled from that of 1950-51 and it has reached a peak of 190 million tonnes which is being maintained. As a consequence of the developments, India was able to achieve relatively self sufficiency in food grains and had made remarkable progress in oil seed and dry farming agriculture. There are still many thrust areas in which our country must now orient its policies in the interest of agricultural growth with special emphasis on sustainability and equity. One such thrust area is to boost the productivity of horticultural crops with particular emphasis on economically important crops like spices which earn sizable foreign exchange for our country.

1.1. Spices - Foreign exchange earner

Spices including seed spices along with end products like spice oils and oleoresins are fetching considerable foreign exchange. The spices and their products have earned foreign exchange worth Rs.409.42 crores through export of 1.76 lakh tonnes (1992-93 - Spices statistics, Spices Board, Kochi). Export of spices has steadily gone up from 20,000 tonnes in 1950-51 to 45,653 tonnes in 1960-61 to 47,906 tonnes in 1970-71 and further to 92,538 tonnes in 1980-81 and to 1,02,170 tonnes by 1989-90.

Spices have multivarious uses in medicinal, aromatic, flavouring and social customs. They add pungency and flavour to the Indian cuisine. Seed spices are used as condiment in Indian cooking and as flavouring agents. The spices are also used on all auspicious social functions in our country. The area and production of certain important spices is given in Table 1.1.

Table 1.1. Area and production of spices (1992-93)

Spice crop	Area (ha)	Production (tonnes)
Pepper	177360	54930
Small cardamom	82400	4250
Ginger	58080	189440
Turmeric	128600	397400
Clove	1945	1760
Nutmeg	36531	3663
Coriander	376200	194500
Cumin	314431	135200

(Source: Advances in Horticulture Vol. 9 plantation and spice crops - Part I)

The total area under spices during 1996-97 was 25.40 lakh hectares and the production was 97.50 lakh tonnes. The targetted annual growth for spices during Ninth Plan is 4.25 per cent as against the targetted over all annual agricultural growth of 4.5 per cent (Agrl. Engg. Today 22(3-4), 1998).

As the spice crops have restricted geographical distribution, the possibility of area expansion is very much limited and the targetted production of spices by 2000 AD can be met only by increasing the productivity through improved varieties and modernising input technologies.

Table 1.2 indicates the target for production of spices by 2000 AD to meet the future demands.

Table 1.2. Targets for production of spices by 2000 AD

Spice crop	1991-92 base level	2000 AD ('000 tonnes)
Pepper (11)	62.0	125.0
Small cardamom (5)	8.5	2.6
Ginger (12)	158.0	405.0
Turmeric (9)	419.0	800.0
Coriander (9)	190.0	370.0

(Data in parenthesis indicate annual growth rate in per cent)

1.2. Yield gap in spices

Table 1.3. gives an idea of yield gap in some annual spices.

Table 1.3. Average and realised yields of some spices

Spice crop	National Average (kg/ha)	Highest recorded yield (kg/ha)
Ginger	2182	11500
Turmeric	2105	14500
Coriander	618	1068

(Source: Advances in Horticulture - Plantation and spice crops Part-I)

The table 1.3 amply indicates the scope for increasing the productivity by about 2 to 6 times the national average. Turmeric is one of the important spice crops which has greater potential for increasing its productivity among the major spices.

1.3. Turmeric - Economically important spice

Turmeric (*Curcuma Longa Linn.*) is one of the major spices cultivated in India, grown largely in Andhra Pradesh, Orissa, West Bengal, Tamil Nadu, Kerala, Assam and Maharashtra. Turmeric earned foreign exchange of Rs.16.6 crores which was 13 per cent of total export earnings from spices products in 1992-93 by export of 6345 tonnes of Turmeric powder (Spices statistics, Kochi).

Tables 1.4 and 1.5 give information on all India and statewise area and production of turmeric for the years 1996-97 and 1997-1998.

Table 1.4. All India area and production of turmeric

	1996-97	1997-98	% decline
Area (000 ha)	135.2	124.6	7.8
Production	528.9	487.6	7.8

(Source: Directorate of Economics and Statistics, Department of Agri. & Cooperation)

Table 1.5. Statewise area and production of turmeric

State	(Area '000 ha)		(Prodn. '000 tonnes)	
	1996-97	1997-98	1996-97	1997-98
Andhra Pradesh	52.0	48.0	292.0	273.0
Arunachal Pradesh	0.5	0.3	1.2	1.0
Assam	10.0	10.1	6.9	7.0
Bihar	3.4	3.1	3.3	3.6
Gujarat	0.4	0.4	11.0	7.4
Karnataka	4.8	4.5	26.2	25.0
Kerala	3.8	3.6	9.1	8.4
Madhya Pradesh	0.7	0.7	0.7	0.6
Maharashtra	7.2	7.3	9.2	9.1
Meghalaya	1.4	1.4	6.4	6.4
Mizoram	0.4	0.4	3.6	3.6
Orissa	19.7	14.3	38.5	28.0
Rajasthan	0.2	0.2	0.8	1.4
Sikkim	0.3	0.4	1.0	1.2
Tamil Nadu	16.0	15.2	92.0	83.7
Tripura	1.4	1.4	2.8	2.8
Uttar Pradesh	0.4	0.8	1.7	1.6
West Bengal	12.6	12.5	22.5	23.6
All India	135.2	124.6	528.9	487.4

There has been a fall of 7.8 per cent both in area and production of turmeric for the country as a whole which has been accounted for mainly by all major turmeric growing states. Tamil Nadu accounted for 12.2 and 11.8 per cent of the total area and 17.2 and 17.4 per cent of production of turmeric during 1997-98 and 1996-97 respectively. This decline in turmeric production is a matter of concern.

1.4. Need for increasing productivity of turmeric

While on one hand, the targetted annual growth rate of 9 per cent for turmeric is being aimed to achieve a production of 8 lakh tonnes by 2000 AD, on the other, there has been remarkable fall in the area and production of turmeric during 1997-98. Unless measures are taken to improve the productivity by adopting modern input technologies in crop improvement, crop production, crop protection and crop processing aspects the turmeric scenario will become unenviable in the near future.

1.5. Mechanisation - Tool for increasing productivity

Mechanisation in agriculture with modern appropriate mechanical technology is one of the tools for increasing productivity along with other high tech genetic, agronomic and plant protection inputs. This has already been proved in major field crops like sugarcane, wheat, paddy and cotton. Tractor and its implements have become essential farming aids in the hands of even small farmers indicating the near total adoption of tractorisation in Indian Agriculture. This mechanisation trend has been geared up in most of the field crops like sugarcane and paddy. Turmeric, being

generally cultivated as a rotational crop with sugarcane and paddy, is also bound to follow this mechanisation trend, the need for which is already felt by the farmers.

1.6. Benefits of mechanised crop production

Mechanisation helps in achieving the required tilth of soil in less time, in land preparation, perfect formation of ridges for planting, timely planting of seed material, timely weeding operations, proper application of crop protection measures, timely harvesting, achieving higher efficiency of harvesting with less cost and obtaining many other tangible and intangible benefits. One important way of improving productivity is to reduce the field losses and damages to the produce at the time of harvest and thus increase the actual yield that has been realised.

1.7. Conventional method of harvesting turmeric

The conventional method of harvesting turmeric rhizome is by digging the clump from the soil with a fork type spade. The operation is highly labour intensive requiring only skilled labour. Since the rhizomes spread down 15 to 20 cm deep in the soil, it will not be possible to achieve digging of the entire rhizome by manual digging and hence considerable quantity of rhizome is left undug. The damage caused to the rhizome by the fork type spade is also considerable.

1.8. Mechanical harvesting of turmeric

The need to improve the yield realised by reducing field losses in turmeric, emphasises the importance to develop suitable mechanical harvesting technology for turmeric. Moreover, the increasing non-availability of skilled labour for this work and

the prevailing higher harvesting charges demanded, make it all the more essential, the need to develop mechanical means of harvesting turmeric.

With tractor already available in the farms, development of a suitable attachment to harvest the turmeric rhizome appear to be the most appropriate mechanical harvesting technology, to satisfy the requirements in harvesting of turmeric namely, to achieve maximum yield realisation with minimum field losses, minimum damage and at lesser cost.

1.9. Objectives of the present study

The study on the design parameters for development of a suitable tractor drawn turmeric harvester is envisaged to cater to the urgent need of the farmers with the following objectives.

1. To optimise the design parameters in terms of soil, crop, tool and operational factors interaction for mechanical harvesting of turmeric to achieve maximum harvesting efficiency with minimum damage to the produce.
2. To design and develop a suitable mechanical harvester.
3. To evaluate the unit in the field for performance.
4. To work out the cost economics of the harvester in comparison with conventional method of harvesting.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

The Scientific information on turmeric harvesting in relation to dynamic behaviour of soil and crop at harvest, the harvesting tool, crop picking and handling mechanism and their operational parameters is very limited. Hence information on such aspects on similar soil working tools and related root crops having a direct bearing on the subject of study is reviewed and presented in this chapter under following headings.

1. Soil - tool interaction models
2. Soil parameters
3. Crop parameters
4. Development of root crop harvesting systems

2.1. Soil - tool interaction models

Soil working tools cause the soil to fail as they move 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 analysing 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 (1956) carried out experiments on rake angle of inclined tools for their performance. They determined the pattern of soil failure front as a crescent shape on soil surface with failure starting from the cutting edge of the tool and expanding into a crescent. They 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 one 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.

Hettiaratchi and Reece (1974) Godwin and Spoor (1977). Mckyes and Ali (1977) and Perumpral *et al* (1983) applied the above technique to narrow tillage tools and they optimised a share lift angle of 20 deg for minimum draft.

Gill and Vanden Berg (1967) also reported that draft forces were 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.

Mckyes and Ali (1977) determined a failure model consisting of a straight rupture plane starting from the cutting edge to the soil surface and they 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. They concluded that the draft force of a soil working tool is directly proportional to the tool width and increases exponentially with operating width.

Harrison (1982) tested inclined blades at various rake angles in a glass sided box and measured the forces on the blades. He observed that the draft had direct relationship with rake angle and depth. The draft increased at a lesser rate upto 30 deg rake angle and increased drastically beyond 30 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.

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. They also suggested that these models could be applied for under 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.

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

Wufsohn et al (1996) discussed agricultural shear strength based models and concluded that soil-water characteristics determine the soil behaviour. They 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 upto 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

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. He also described the rhizome of turmeric as having multilayered, thin walled cells in radial rows forming the cork tissue.

Burkill (1966) observed that the primary tuber at the base of axial stem of turmeric crop is ellipsoidal, about 5 cm by 2.5 cm bearing many rhizomes, 5-8 cm long, 1.5 cm thick, straight or little curved, with secondary branches in two rows, which may have tertiary branches, the whole forming a dense clump.

Rama Rao *et al* (1975) described that in harvesting turmeric crop, the rhizomes are not to be bruised or damaged and that the whole clump is to be lifted out.

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.

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 turn yellow.

The leafy top is cut off and the roots are removed by digging out and all adhering earth is shaken or rubbed off, the rhizomes are then well washed with water. The yields of fresh raw turmeric varies from 16.8 to 22.4 tonnes per hectare for irrigated crop and 6.72 to 8.96 tonnes per hectare under rainfed condition.

Preliminary studies reported by Krishnamurthi *et al* (1975) showed that the colour content increased during the first two months of harvesting season and subsequently tended to decrease. They 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 differ according to the particular cultivar and the location of cultivation.

The curing percentage is largely a varietal character ranging from 16 to 21 per cent. Curcumin ($C_{21}H_{20}O_6$) is the principal colouring constituent which imparts characteristic yellow colour to turmeric (Narayanan *et al* 1982).

Mathai (1976) reported that curcumin content varied depending on stage of harvest and varieties. Sivaraman (1992) identified number of tillers, number of mother rhizomes, 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, cassava etc. 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.

2.4.1. Potato

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.

Pratapsingh 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.

Misener *et al* (1984) designed a two row potato digger to dig, lift and load the potatoes. The digger blade shape was 250 x 130 x 60 mm high carbon steel which oscillated about the centre point.

Ganshyam Das and Avinash Agarwal (1985) developed a concave shaped share plate for potato digger attachment to country plow.

Sharma and Verma (1986 a and 1986 b) 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 510 x 260 x 8 mm and for a single row operation the draft required was 80 to 105 kg. As the forward speed increased from 35.7 to 74.6 cm / sec, the damage to tubers increased from 0.3 to 0.7 per cent and the undug tubers increased from 6.6 to 14.4 per cent.

Mcleod *et al* (1989) utilised the concept of elevating potatoes and adhering soil from digging shares to design improved potato harvesters.

Kang and Halderson (1991) also designed a two row vibrating blade potato digger and they found that increased travel speed decreased shatter bruise and black spot of potatoes because of 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 per unit area of furrow slice was 3.3 to 4.2 N/cm² for 1.7 to 3.3 kph 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.

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.

Anon (1974) evaluated a tractor drawn groundnut digger of PAU model which had a 122 cm long digger blade to uproot the crop.

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.

Ali *et al* (1979) discussed about a few designs of groundnut diggers developed by the research institutes in India to reduce the draft and clogging plants. These diggers were essentially variations of blade harrow having different sizes and curvatures.

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 remain after harvesting was elevated by a pick up digger that shook most of the loose soil.

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.

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.

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.

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.

Maraviya *et al* (1988) determined that the draft requirement was 95.25 kg 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 one pass.

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.

Dawelbeit (1993) studied the effect of mechanical shaking of groundnut on combining losses in heavy clay soil and found that the heavy clay particles adhering to groundnut pods, created problems in combining.

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

$$S_d = (P_t - P_{d_{PTO}} R_d) T_{eff} / (D_d R_d + W_d C_r)$$

where

S_d = Digging speed, kph

P_t = Tractor power available, kW

$P_{d_{PTO}}$ = PTO Power requirement of digger, kW per row

R_d = No of rows

T_{eff} = PTO to Draw bar power transfer efficiency, fraction

D_d = Draft requirement of digger, N per 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.

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. The ridger type was observed to be the most suitable.

Duraisamy and Balasubramanian (1998) investigated a groundnut crop picker - conveyor attached to a tractor drawn digger blade. Two typical tools of geometry, inverted-V and crescent, at different rake angles from 5 to 20 deg and approach angles from 0 to 15 deg were evaluated. Maximum harvesting efficiency was achieved at 15 deg rake angle and 0 deg approach angle. The draft varied from 236 to 250 kg in sandy loam to loamy sand soils.

2.4.2.1. Factors affecting harvesting loss

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

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.

Dawelbeit (1992) observed that the harvesting losses were largely contributed by pre-combining losses. Dawelbeit (1993) studied the effect of mechanical shaking of groundnut combining losses and concluded that extra shaking reduced the combining losses by decreasing pre-combine and header losses.

2.4.3. Onion

Wayne Lepori and Pricehobgood (1970) studied about a mechanical harvester for fresh market onions which consisted of a digging blade, a belt lifter and topper.

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

Jadhav *et al* (1995) fabricated a low cost self propelled onion digger windrower powered by a 5 hp 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 2.63 to 3.45 per cent and digging efficiency was 89.66 to 93.23 per cent.

Sandeep Mann and Sudama Aggarwal (1998) successfully tested the tractor drawn potato digger with a '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 hoe (V-shaped) mounted at the rear of the tractor. The rake angle was 25 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 per cent respectively.

Anon (1990) reported the cassava digger and sweet potato and turmeric lifter developed by Carib Agro Industries Ltd, Barbados. 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.

2.4.5. Turmeric

Murugesan and Tajuddin (1995) developed a turmeric digger with two digger blades of size 825 x 150 x 10 mm joined together for proper penetration and to reduce draft. The tubers were left in soil without inversion.

2.4.6. 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 sloped 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 R 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. They reported less damage and greater recovery of sweet potato tubers by mechanical harvesting.

2.4.7. 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 12 inches into the soil below the beets.

Guelle (1946) analysed a Mc 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/sec, the draft increased with shares having a negative cut angle. The draft increased with working depth.

Srivastava *et al* (1978) studied about three row tractor drawn sugar beet digger and used sweeps as lifting shovels at a spacing of 150 to 200 mm. The harvesting efficiency was 98.80 per cent and the damages were about 1 per cent.

Tarachandra Thakur *et al* (1980) conducted experiment on a 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 kph.

2.5. Economics of mechanical harvesting

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 per ha which was half of that of digger with corrugated roller while it was

150 man-h per ha for manual harvesting. The cost of harvesting was Rs. 246 to 262 per ha for mechanical diggers as against as Rs. 375 per ha for manual harvesting.

Dawelbeit (1991a) found out from his studies that the labour requirement for manual harvesting and fully mechanized 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 per tonne by manual harvesting to 20 man h / tonne by mechanical harvesting.

Duraisamy (1997) observed that the cost of operation of a tractor drawn groundnut harvester was Rs.600 per ha as against Rs.880 per ha by manual harvesting with a saving of 31.74 and 95.98 per cent in cost and time respectively. The break even point for the harvester was 17 ha per annum.

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.

Turmeric:

Murugesan and Tajuddin (1995) worked out the cost of digging by tractor drawn turmeric digger to be Rs.575 per ha as against Rs.300 per ha by manual digging.

Onion:

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

It is seen from the above review, that though information on various aspects of mechanical harvesting of turmeric is meagre, 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 - rake angle, tool shape, approach angle of tool and soil lifters

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.,



MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

In this chapter, the present practices and methods used for harvesting of turmeric and the experimental methodology used to investigate the dynamic behaviour of the different components of the harvester as influenced by soil, crop, machine and operational parameters, are discussed.

The materials and methods used to identify appropriate harvesting tool, the tool penetration, lifting up of crop and the design of the harvesting system are also explained. The details of performance evaluation and cost economics are also outlined.

3.1. Turmeric crop

Turmeric (*Curcuma longa*. Linn.) is an erect perennial herb but is grown as an annual crop (Plate 3.1). The primary tuber at the base of aerial stem is ellipsoidal about 5 cm by 2.5 cm bearing many rhizomes 5 - 8 cm long, 1.5 cm thick, straight or a little curved, with secondary branches in two rows, which may have tertiary branches, the whole forming a dense clump. The rhizomes are brownish and scaly outside and inside is a bright orange colour. The young tips are white. The roots are fleshy, often ending in a swollen tuber of 4 cm by 2 cm.

The leafy shoots grow upto 1 m in height and are erect, bearing 6-10 leaves with the leaf sheaths forming a pseudo stem. The thin petiole is rather abruptly broadened to the sheath. The inflorescence is a cylindrical spike terminal on the leafshoot (Plate 3.2).

Plate 3.1. Fully grown turmeric crop stand in field

Plate 3.2. Turmeric plant with inflorescence

A number of varieties are distinguished in India by names of the localities in which they are grown. The common varieties in Tamil Nadu are Chinnanadan and Perumnadan grown in Bhavani and Erode taluks. They are also known as Erode and Salem varieties. BSR-1 is a mutant variety.

Turmeric is cultivated in areas where rainfall is adequate or facilities for irrigation are available. It requires a hot and moist climate. Turmeric thrives best on loamy or alluvial, loose, friable and fertile soils and can not with stand water logging.

The mother rhizome is used as seed material. The crop can be planted on flat beds or on ridges. In Tamil Nadu it is planted on ridges, 20 to 25 cm high and 45 to 60 cm broad. The planting distance is normally 20 to 30 cm at a depth of 7.5 cm. The usual planting time is May - June and the crop will be ready for harvest in about 9 to 10 months.

In harvesting turmeric crop, care should be taken that the rhizomes are not cut or bruised and that the whole clump is lifted out with dry plant, including the base of the stems. The leafy tops are cut off a week prior to harvest and the crop is given a wetting. The rhizomes are dugout after a week with a spade, the roots are removed and all adhering earth is rubbed off, and the rhizomes are then washed with water. The fingers or daughter rhizomes are separated from the rounds or mother rhizome. The yield of a fresh raw turmeric varies from 16,800 to 22,400 kg/ha in case of irrigated crop and 6720 to 8960 kg/ha under rainfed conditions (Chadha and Rethinam, 1994). The rhizomes are subjected to a process of curing and polishing. The yield of turmeric from raw material varies from 15 to 20 per cent. The most important factors on quality

of dried turmeric is the intrinsic characteristics of the variety grown and the stage of maturity of rhizome at harvest.

3.2. Conventional method of harvesting

Studies were made to assess the capacity, cost and economics of harvesting of turmeric by conventional method. The yellowing of the leaves indicates the maturity of the rhizomes underground (Plates 3.3, 3.4 and 3.5). The conventional practice is to cut the leaf shoots upon maturity and slightly wet the field. The turmeric rhizomes are dugout after a week by skilled labour with a special fork type of spade / pick axe (Plate 3.6). Normally turmeric digging is done by migratory contract labour who demand very high wages during peak season. The charges demanded are Rs.7000 to Rs.8000/ha and the damage caused to rhizome by the fork type spade is 10 to 15 per cent because the labour has to digout the clump all around and in doing so, the fork bruises the rhizome every time it hits the rhizome.

A turmeric field having an area of 0.6 ha was selected. The field was subdivided into 6 plots, each having 1000 square metre area. Each plot was manually harvested, simultaneously recording time taken and number of persons employed. In each sub plot, an area of 1 sq. metre was marked at random in three places. Then the plants were harvested from each sample area. The weight of rhizomes collected from the clump, and damages to the rhizomes were recorded. The rhizomes left undug in the soil were separately collected and weighed.

Plate 3.3. Turmeric crop at maturity - top leaves being cut off

Plate 3.4. Cut foliage spread over field for drying

Plate 3.5. Turmeric field left with rhizome in soil ready for harvest

Plate 3.6. Conventional method of digging with fork type spade

3.2.1. Harvesting efficiency

The harvesting efficiency was calculated using the following formula :

$$\eta_{ch} = \frac{W_r}{W_r + W_s} \times 100 \quad \dots\dots\dots 3.1$$

where,

- η_{ch} = Harvesting efficiency, per cent
- W_r = Weight of rhizomes collected from harvesting clump in one square metre area, kg
- W_s = Weight of undug rhizomes collected from the soil in one square metre area, kg

From the data collected from each plot, the coverage, cost of harvesting and harvesting efficiency were calculated. The information thus calculated was evaluated and compared with the data obtained from turmeric harvester developed under this study.

3.3. Soil parameters

The soil properties that may have influence on the design of tool for harvester were identified as soil type, soil moisture, bulk density, and cone index.

3.3.1. Soil type

Turmeric crop is generally grown in light and medium soils and hence two types of soil from predominantly turmeric cultivated areas in Coimbatore region, namely Red sandy loam in Bhavanisagar and Clay loam in Thondamuthur regions were selected for the study. The experiments were conducted in the farm of Agricultural Research Station, TNAU, Bhavanisagar and private farms in Thondamuthur region. Soil samples at six different locations in each field were taken.

3.3.2. Soil moisture

Soil moisture plays an important role for the growth of turmeric and an optimum soil moisture is needed at the time of harvest to minimise field losses and energy input. Soil samples at 15 to 20 cm depth during harvest in ten different locations at random was taken and moisture content on dry basis of soil was determined by gravimetric method and the mean value was used in the study. The general practice in conventional method of harvesting is to wet the crop after removal of the cut foliage which are spread in the field for drying. The digging is done after 5 to 7 days of irrigating the field. To find out the optimum soil moisture level suitable for mechanical harvesting, experiments were conducted at three different moisture levels namely, after irrigating the field 3, 7 and 12 days prior to harvest of the crop. All the tests for the different combinations of the tool variables were carried out at the optimised soil moisture level only.

3.3.3. Bulk density

Bulk density of the soil is a measure of compaction of the soil condition influencing tool parameters. Bulk density was measured to define soil condition. The volume of undisturbed soil core from field during harvest was taken at six places at random and mass per unit volume was calculated by means of core sampler method.

3.3.4. Cone index

Cone index is a measure of penetration resistance of the soil. Hence it was measured at a depth of 0 to 200 mm to define soil condition. The cone index of soil was measured by using Vicksberg Cone Penetrometer (Plate 3.7) having a base area of

5 square cm and 30 deg apex angle. The proving ring capacity of the penetrometer was 100 kg and the 0.002 mm dial indicator provided in the unit indicated that penetration load applied with a sensitivity of 0.1 kg per division. The cone index was measured at ten different places selected at random during harvest.

3.4. Crop parameters

The crop parameters influencing mechanical harvesting of turmeric are plant population, crop spacing, rhizome weight, rhizome spread vertically and laterally, moisture content of rhizome and bulk density of rhizome.

The physical nature and condition of the crop may vary with variety. The study was conducted with Salem, Erode and BSR-1 varieties of turmeric predominantly cultivated in Tamil Nadu. The varietal characters of these varieties are given in Table 3.1.

Table 3.1. Varietal characters of turmeric

	Variety		
	Erode	Salem	BSR-1
Foliage	Plants are vigorous and tall	Plants are vigorous and tall	Green and tall
Rhizome	Short, slightly bent	Bigger	Bigger with medium fingers
Curing, per cent	16 - 20	16 - 20	18 - 20.5
Curcumin, per cent	3.9	4.75	4.2
Yield, t / ha	20 - 22	20 - 22	29 - 31
Duration at maturity, days	270 - 280	270 - 280	280 - 290

(Source: Chadha and Rethinam, 1994; Edison *et al* 1991 and Kumar *et al* 1997)

The turmeric plant has an average of 2 to 5 tillers per hill depending on variety and there will be a number of fingers in each plant. The mother rhizome will be larger and daughter rhizomes or primary fingers branch out from the mother rhizome and tertiary fingers branch out from the daughter rhizomes (Plate 3.8).

3.4.1. Plant population

The population of crop is an important parameter in determining the volume of crop handled by the machine per unit width of tool per unit time and speed. Average value of population of crop in one square meter area at six different locations for each variety was measured.

3.4.2. Crop spacing

There are two systems of planting followed for turmeric, flat bed and ridges and furrows. In Tamil Nadu, turmeric is planted in ridges. The spacing adopted between rows is 45 to 60 cm and 20 cm between plants in ridge and furrow system of planting (Kumar *et al.*, 1997). The harvesting unit is designed to adjust for row spacings between 45 and 60 cm (Plate 3.9).

The spacing adopted for the three varieties in this study are

Erode - 45 x 20 cm

Salem - 45 x 20 cm

BSR-I - 60 x 20 cm

3.4.3. Rhizome spread

The harvesting / digging tool interaction in the soil is coupled with uprooting the rhizome with roots. The spread of rhizome laterally and vertically in the soil varies with the varieties.



**Plate 3.7. Soil penetration resistance being measured with
*cone penetrometer***

**Plate 3.8. Freshly dugout clump with mother rhizome and primary
and secondary fingers and roots**



Plate 3.9. Adjustment of distance between blades with spacer to align with ridge distance

Fig. 3.1 illustrates the spreading pattern of rhizome of turmeric in the soil. This 40 is a very important parameter in the design of the digging tool. The rhizome spread of ten clumps selected at random in each of the major varieties, Erode, Salem and BSR-I was measured using a scale by digging the soil adjacent to the plant on the ridge. The data was tabulated and the mean value was calculated.

3.4.4. Rhizome weight

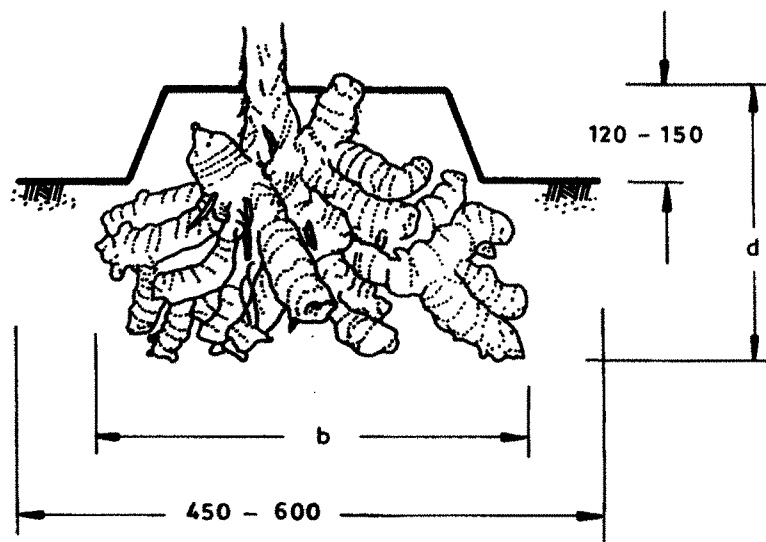
The weight of rhizome is an important crop parameter and it varies from 100 to 300 g for different varieties of turmeric. Soil is adhered all around the rhizome and when it is dug out, the rhizome is with soil all around it. So the weight of rhizome with the soil as it was lifted and thrown back (without inversion) by the digger blade was measured and the data was tabulated. The rhizome without soil also was weighed.

3.4.5. Moisture content of rhizome

The moisture content of freshly harvested turmeric rhizome is generally high at about 70 to 80 per cent. The samples from the field were taken for analysis of moisture content for the three varieties in the study and moisture content was determined by gravimetric method on dry basis.

3.4.6. Number of fingers per hill

Each hill has one or more mother rhizomes or bulbs and from that the daughter rhizomes or primary fingers branch out numbering 4 to 10. The secondary fingers are 8 to 20 in number. The total number of fingers per hill influence the volume of crop to be handled. The number of fingers were counted from 10 harvested hills selected at random.



VARIETIES

	<u>ERODE</u>	<u>SALEM</u>	<u>BSR-I</u>
d	176	192	163
b	240	255	283

Fig.3.1. SPREAD OF TURMERIC RHIZOME IN SOIL

3.4.7. Bulk density of rhizome

The whole rhizome bulk density is a measure of the volume and quantity of the crop handled by the machine. For measuring this, a container of known volume of inner dimensions 500 x 500 x 500 mm was taken. It was weighed in a balance. Then it was completely filled with freshly harvested rhizomes and it was weighed again. The bulk density was calculated by using the formula,

$$B_R = \frac{W_{tc} - W_c}{V_c} \quad \dots\dots\dots 3.2$$

where,

- B_R = Bulk density of rhizome kg m^{-3}
- W_{tc} = Weight of container filled with rhizomes, kg
- W_c = Weight of empty container, kg
- V_c = Volume of container, m^3

The bulk density was measured from five samples and the mean value was calculated.

3.5. Tool and operational parameters

Harvesting of turmeric rhizomes mechanically is an operation in which the whole rhizome has to be dugout from soil without detaching or damaging the fingers from the clump, by loosening the soil with a tool and then the harvested rhizome with soil has to be lifted up and dropped back. The soil and crop parameters determine the effectiveness of tool penetration for loosening and lifting the soil and the turmeric rhizome, above the tool in its forward motion.

The main parameters of the tool are geometry of tool, tool width, tool length perpendicular to travel direction, rake angle, and depth of operation (Hettiaratchi and Reece, 1974).

The general requirements for the design of the mechanical harvesting system are:

1. The power unit of the machine must be able to pull the harvesting implement at required speed under full load.
2. The row to row spacing of the crop varies from 0.45 to 0.6 m and hence the unit should have provision for altering the center to center distance between the blades to match the row spacing adopted for different types of turmeric crop. A design spacing of 0.45 m which is normally adopted for most of the turmeric varieties, was considered for the design.
3. The tool should be able to penetrate the required depth into the soil to digout the whole rhizome clump.

3.5.1. Selection of prime mover

To select the suitable prime mover, the total power required for operation of the implement should be known. The total power required is the sum of power required for digging the rhizome and dropping it back ; and power required for pulling the implement.

a) Power required for digging the soil and clump

The common row spacing adopted is 0.45 m and hence the width of cut for a single blade was taken as 0.45 m and to digout simultaneously two rows over a total

width of 0.90 m, two digger blades were selected. The maximum depth of operation required is 0.20 m.

$$\begin{aligned} \text{Area of cross section of soil dugout by tool} &= \text{depth} \times \text{width} \\ &= 0.20 \times 0.90 \\ &= 18 \times 10^{-2} \text{ m}^2 \end{aligned}$$

$$\begin{aligned} \text{The maximum unit draft of the soil was assumed as} &= 0.103 \times 10^6 \text{ N/m}^2 \\ &\text{(Smith, 1968)} \end{aligned}$$

Since the implement is operated in the soil which is relatively loose compared to unploughed field, the unit draft is taken as 80 per cent of the assumed value.

$$\begin{aligned} \therefore \text{unit draft} &= 0.103 \times 10^6 \times 0.8 \\ &= 82400 \text{ N/m}^2 \end{aligned}$$

$$\begin{aligned} \text{Soil resistance for cutting} &= \text{Unit draft} \times \text{Area of cross section of soil cut} \\ &= 82400 \times 18 \times 10^{-2} \\ &= 14832 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Assuming the forward speed of tractor} &= 2.5 \text{ kph (0.70 m/s)} \end{aligned}$$

$$\begin{aligned} \text{Power required} &= \text{Draft} \times \text{speed} \\ &= 14832 \times 0.7 \\ &= 10382 \text{ W} \\ &= 10.382 \text{ kW} \end{aligned}$$

b) Power required for pulling implement

$$\begin{aligned} \text{Total weight of the implement with hitch frame} &= 1750 \text{ N} \end{aligned}$$

$$\text{Force required to pull the unit, } F = \mu R$$

$$\begin{aligned} \text{where } \mu &= \text{co-efficient of friction} \\ R &= \text{Weight of the unit, N} \end{aligned}$$

Coefficient of friction was taken as 0.8 (Kepner *et al.*, 1987)

$$\begin{aligned} \therefore F &= 0.8 \times 1750 \\ &= 1400 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Power required for pulling the implement} &= \text{Force} \times \text{speed} \\ &= 1400 \times 0.7 \\ &= 980 \text{ W} \\ &= 0.98 \text{ kW} \end{aligned}$$

$$\begin{aligned} \therefore \text{Total power requirement} &= 10.382 + 0.98 \\ &= 11.362 \text{ kW} \end{aligned}$$

The drawbar power available in a 35 hp tractor is 16.56 kW as predicted by Zoz (1974).

Hence the power required to operate the machine will be adequately provided from the drawbar of a 35 hp tractor.

3.5.2. Material design

The dimensions and materials of critical components namely blade and shank were designed.

a) Design of digger blade thickness

The digger blade was assumed as a simply supported beam, supported by two shanks at its sides.

$$\begin{aligned} \text{Resistance force for cutting for one blade} &= \frac{14832}{2} \\ &= 7216 \text{ N} \end{aligned}$$

The blade was made of mild steel with following dimensions

$$= 0.45 \text{ m} \times 0.25 \text{ m}$$

$$\begin{aligned} \text{Draft /unit length, } w &= \frac{7216}{0.45} \\ &= 16035 \text{ N/m} \end{aligned}$$

$$\begin{aligned} \text{Maximum bending moment} &= \frac{wl^2}{8} \\ &= \frac{16035 \times 0.45 \times 0.45}{8} \\ &= 405.9 \text{ Nm} \end{aligned}$$

Allowable bending stress for mild steel section. $f = 120 \times 10^6 \text{ N/m}^2$ (Anon., 1994)

Flexural formula states, $M/I = f/y$

where, $M =$ Bending moment
 $I =$ Moment of inertia

$$I = \frac{bt^3}{12}$$

where $b =$ width of blade, m
 $t =$ thickness of blade, m
 $y =$ $t/2$

$$I = \frac{0.25t^3}{12} = 0.021t^3$$

\therefore as per flexural formula,

$$\frac{405.9}{0.021 t^3} = \frac{120 \times 10^6}{t/2}$$

$$\frac{405.9}{0.021t^2} = 120 \times 10^6 \times 2$$

$$\begin{aligned}
 t^2 &= \frac{405.9}{0.021 \times 120 \times 10^6 \times 2} \\
 &= 80.5 / 10^6 \text{ m}^2 \\
 t &= 0.0089 \text{ m} \\
 \therefore t &= 8.9 \text{ mm}
 \end{aligned}$$

So a mild steel plate of thickness 10 mm was selected for the digger blade.

Therefore the dimensions of the digger blade were 450(l) x 250(b) x 10(t) mm

b. Design of shank

The digger blade shank was assumed to be made of mild steel flat of length 600 mm and section 75 mm thickness x b mm width.

Considering the shank as a cantilever beam mounted on the main frame of the implement, the bending moment in the dangerous section will be

$$M = R_x \times H = qBdH/n \quad (\text{Bosoi } et \text{ al.}, 1987)$$

where, H = Arm length = 0.60 m

R_x = Horizontal component of resultant force applied at the blade

q = Unit draft = 82400 N/m²

B = Operating width = 0.45 m

d = Depth = 0.20 m

n = Number of blades = 1

Since there are two shanks supporting each blade, it can be approximately assumed that the force acting on the blade can be divided by 2.

$$\therefore \text{Bending moment} \quad M = \frac{qBdH}{2 \times n} \text{ Nm}$$

$$= \frac{82400 \times 0.45 \times 0.2 \times 0.6}{2 \times 1}$$

$$M = 2224.8 \text{ Nm}$$

Moment of inertia of the weakest section, $I = bt^3/12$

where, b = width of section
 t = thickness of section = 0.075 m

$$\therefore I = \frac{b \times 0.075^3}{12}$$

$$= 3.515 \times 10^{-5} b$$

Safe bending stress, $f = 120 \times 10^6 \text{ N/m}^2$

$$y = t/2 = 0.075 / 2$$

$$= 0.0375 \text{ m}$$

By flexural formula,

$$M/I = f/y$$

$$\frac{2224.8}{b \times 3.515 \times 10^{-5}} = \frac{120 \times 10^6}{0.0375}$$

$$\therefore b = 0.0117 \text{ m}$$

$$= 11.7 \text{ mm}$$

Therefore, $b \approx 12 \text{ mm}$

The shank was made of mild steel flat of section 75 x 12 mm and 600 mm length.

3.5.3. Constructional features

The harvesting unit has to be designed as a rear mounted attachment to a 35 hp tractor utilising the standard three point linkage available with tractor.

A standard tractor mounted cultivator frame with hitch arrangement was selected for the main frame of the attachment. The main frame was made of standard channel section of size 75 x 40 x 7.3 mm (ISMC 75). The size of the main frame was 2120 x 600 mm.

Four mild steel plates of size 200 x 150 x 12 mm were welded vertically to the bottom of the cross members in the frame to serve as brackets for mounting the digger blade shanks. Holes were drilled in the brackets for mounting the shanks at different rake angle position.

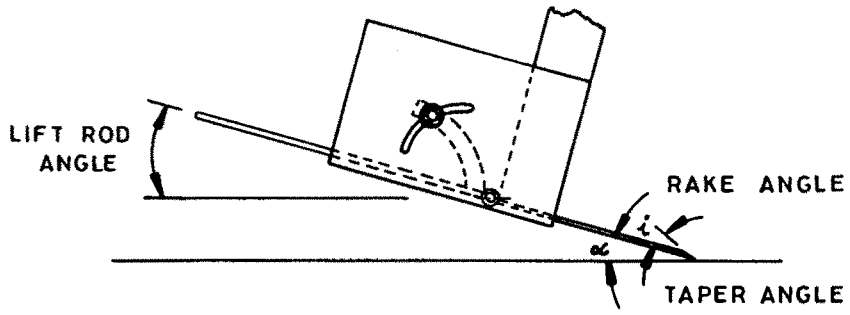
The bottom end of the shank was bent 90 deg to mount the digger blade on the shank horizontally. The blade was supported at both the ends by the shanks.

3.5.4. Tool variables

The important tool variables as described by Hettiaratchi and Reece (1974) that may have bearing on the performance of the digger harvester are described below :

a) Tool geometry

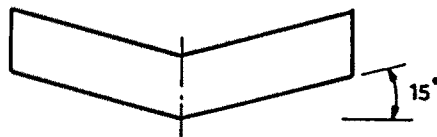
The shape of tool penetrating and loosening the soil has a direct effect on the force required to pull the tool for easy flow of soil and crop over the surface of the blade without upheaval or ridging (Klenin *et al.*, 1985). To study the effect of tool shape, three types of tools were used (Fig.3.2). The tools used were; straight, crescent and inverted-V shaped blades. The depth of penetration at the centre as well as at the



CRESCENT



STRAIGHT



INVERTED 'V'

Fig.3.2. TOOL GEOMETRY SHAPES
NOT TO SCALE

ends is governed by inversion angle of tool (Approach angle - angle perpendicular to the direction of travel of tool). Higher and higher the approach angle, greater will be the variation in the depth of operation at the centre and at the ends. Hence a lower level of approach angle to a maximum of 15 deg for inverted V shaped tool was selected for the study. The variation in depth of penetration of the tool from the centre towards the end is less when the rake angle is minimum.

b) Tool width

The tool has to loosen the soil easily and moreover the loosened soil and uprooted crop have to slide over the tool backwards to avoid bulldozing effect. A tool geometry with 10 mm thickness and 250 mm width at the centre was used through out the study. The width of the tool was fixed as 250 mm to keep within the limit for a narrow blade, as specified by Luth and Wismer (1971). The front edge tip face was tapered to have a taper angle of 25 deg in all the tools.

c) Tool length

The tread width of a 35 hp tractor is kept at 1550 to 1600 mm normally and the rear wheel centre to centre distance is kept at 1350 mm. Two digger blades each of 450 mm length as designed for a 35 hp tractor were mounted on the frame in such a way that the outer edge of each blade was just behind the centre of the rear wheel, leaving a ridge (450 mm wide) in the middle, between the inneredges of the two blades. The forward movement of the tractor in the field with its rear wheels running on the ridge did not cause any damage to the rhizome.



When the tractor moves forward with its rear wheels on the ridge, two alternate rows of crop will be dug out, leaving a row undug in the middle which will be dug out in the next pass. Fig.3.3. illustrates the alternation field machine pattern adopted in the field with the sequence of digging operations patterned in such a way that the tractor wheels do not run over the harvested rows at any point of time.

d) Rake angle

It is the suction angle of the soil-tool interface measured along the direction of travel into the horizontal soil surface. The draft is proportional to the weight of soil ridge formed by deformation (Klenin *et al.*, 1985) which is in direct proportion to this angle. All the tools were mounted on the shanks at zero deg rake angle. Bolt holes provided in the shanks for turning the tool backward facilitated to set the rake angles. Many workers on soil working tools have optimised 20 deg as appropriate rake angle for minimum draft in narrow tools. Duraisamy (1997) optimised 15 deg rake angle for groundnut harvester. Slightly higher rake angles were selected for this study as the tool has to penetrate upto 200 mm deep in the soil to digout the rhizomes. Hence three levels of rake angle namely 15, 20 and 25 deg were selected for the study.

e) Lift rod length

The lift rod provided at the rear of the digger blade has to handle the harvested rhizome with soil that is being pushed up by the digger blade and drop it at the rear. The length of lift rod is to be optimised to achieve quicker pushing back of the clump and soil without bulldozing effect, at lesser draft. The lift rod length normally used for groundnut and potato diggers was 200 to 250 mm (Maraviya et al 1998, Duraisamy & Balasubramaniam 1998 and Sharma & Varma 1986a,b). Hence three levels of lift rod length namely 150, 250 and 350 mm were used for studying the performance.

f) Lift rod angle

The inclination of the lift rod also plays an important role in checking the bulldozing effect and delivering the rhizomes and soil quickly to the rear. In potato and groundnut diggers 5 to 10 deg was used for lift rod angle (Duraisamy & Balasubramaniam 1998 and Sharma & Varma 1986a, b). Hence three levels

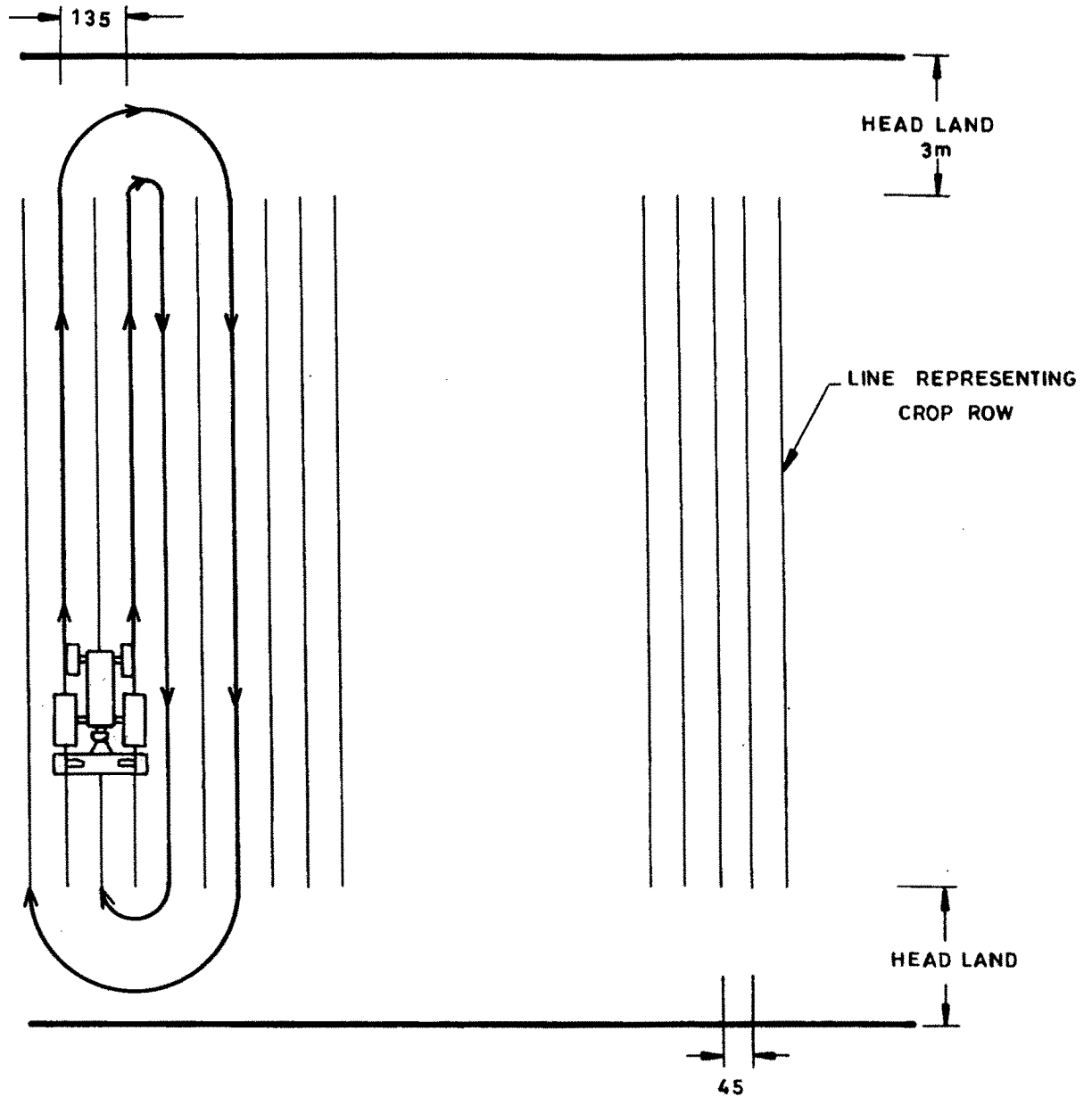


Fig.3.3. ALTERNATION FIELD MACHINE PATTERN FOR TURMERIC HARVESTING

of the lift rod angles namely, -5, 5 and 15 deg which could be varied by adjusting the hinge position of the lift rod base with the digger blade, were selected for the study.

3.5.5. Operational parameters

a) Speed of operation

The speed of operation affects the draft of the soil working tool by the accelerating component of the soil particles. Due to operational restrictions in the cropped field, the speed was fixed at 2.5 kph which is the normal speed of the harvester for all the factor levels required (Kepner *et al.*, 1987).

b) Depth

The depth of operation helps to decide the tool parameters for the operational limitations like draft, speed and width. Based on the study on the vertical spread of rhizome in the soil, the desired depth of operation was fixed at 200 mm for the experiments.

3.6. Instrumentation for draft measurement

The draft was measured by adopting a strain gauge transducer load cell dynamometer powered by 6 volt dual dry cell power supply and processed by an instrumentation amplifier to a specially calibrated volt meter (Plate 3.10) (Divakar Durairaj, 1995). The calibration chart of the load cell dynamometer is given in Fig. 3.4.

The test was run by connecting the load cell dynamometer between the test tractor hitched with digger attachment and the hauling tractor (Anon., 1983). The test tractor was run with the transmission in neutral position and the hydraulic system fully operational. The load cell was connected in such a way to ensure horizontal pull. The

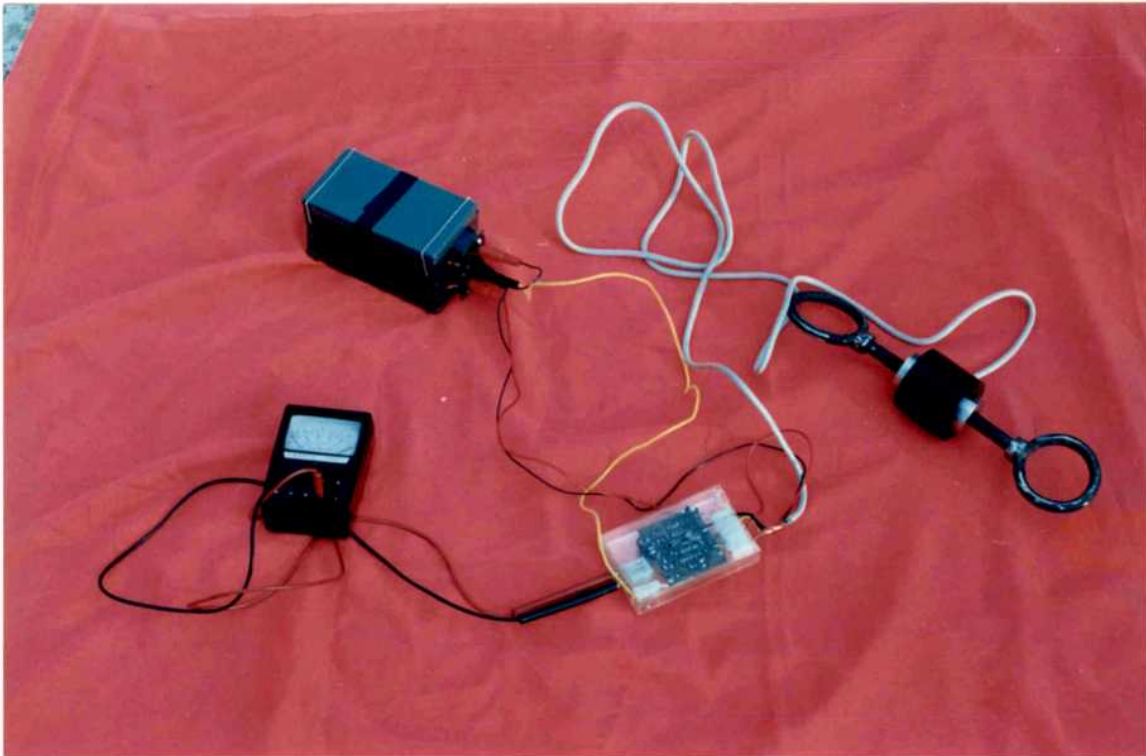


Plate 3.10. Instrumentation for draft measurement showing 6 volt Dual power supply, load cell, instrumentation amplifier and volt meter

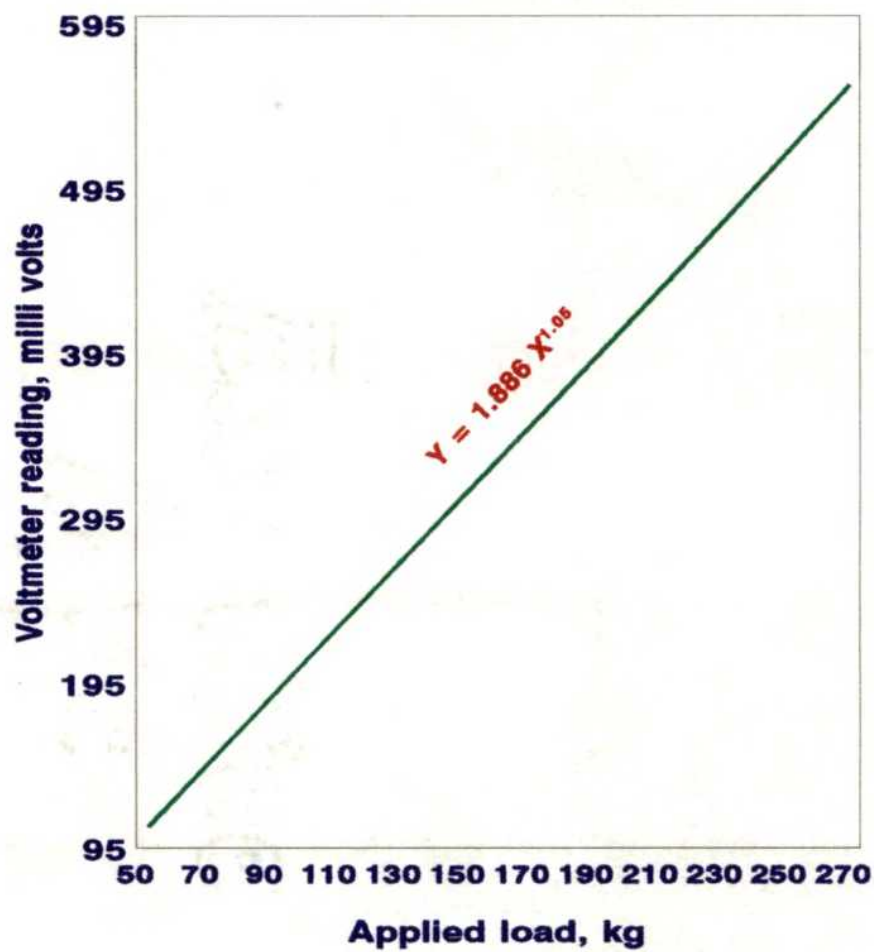


Fig.3.4 Calibration chart of load cell dynamometer

rolling resistance of the test tractor under each test condition was measured by towing the tractor with the implement in the raised position. The draft requirement was evaluated by subtracting the rolling resistance from the gross pull measured. The readings were obtained in millivolts and the draft was calculated from the pre-calibrated chart. Each test was replicated three times for all the levels of variables tested.

3.7. Effect of tool and operational parameters on harvesting

The performance of the tools was studied by conducting the tests with all the levels of the variables as presented in Table 3.2. in clay loam soil at the soil moisture content optimised by experimentation.

Table 3.2. Levels of variables for performance of tools

Soil type	Tool geometry	Rake angle, (deg.)	Lift rod length (mm)	Lift rod angle (deg.)
	Straight - T ₁	15 - A ₁	150 - R ₁	-5 - M ₁
Clay loam	Crescent - T ₂	20 - A ₂	250 - R ₂	5 - M ₂
	Inverted V - T ₃	25 - A ₃	350 - R ₃	15 - M ₃

Replication : 3

Total : 3 x 3 x 3 x 3 = 81 treatments

3.7.1. Experimental procedure

The straight blade was mounted on the shanks at the rake angle, lift rod length and angle chosen by the random number and the shanks were fixed to the frame which was mounted to the tractor three point hitch. The tractor was moved slowly, simultaneously lowering the tool upto desired depth of penetration of 200 mm and the lift rod length was kept at either 150 or 250 or 350 mm and the lift rod angle was set either at -5 or 5 or 15 deg; and the rake angle level of 15 or 20 or 25 deg were set as per the random number allotted to all variable level combinations and replications. The

desired rake angle setting was done by choosing the appropriate hole position in the shank and the matching hole in the mounting bracket of the main frame. The lift angle was set by adjusting the hinge position of the lift rod base in the blade (Plates 3.11 and 3.12). There were 81 treatment-replication combinations for each type of blade. Then the tractor was set at neutral position and the tractor with tool mounted was connected to another tractor with load cell in between (Plate 3.13). Then the gear position and throttle in the hauling tractor was set for a forward speed of 2.5 kph. The tractor with lowered position was towed for 50 metres run. The readings from the load cell were recorded instantaneously and the average value of several readings was calculated (Plate 3.14). The time taken to cover the distance was taken. The harvesting efficiency was determined as explained in Sec. 3.2.1. The percentage of damaged or cut rhizomes in the harvested crop was found out by sampling 20 rhizomes at random and counting the number of damaged / cut rhizomes.

Percentage of damaged rhizomes,

$$D = N_c / N_t \times 100 \quad \text{.....3.3}$$

where,

D = Damaged rhizomes, per cent

N_c = Number of damaged rhizomes

N_t = Total number of rhizomes in the sample

The above procedure was replicated thrice and all readings were tabulated.

The above experiment was repeated for other shaped blades namely, crescent and inverted-V shaped tools by following the randomizations procedure.

An experiment with Factorial Completely Randomized Design (FCRD) was laid out with random numbers. The factors considered and their levels are given in

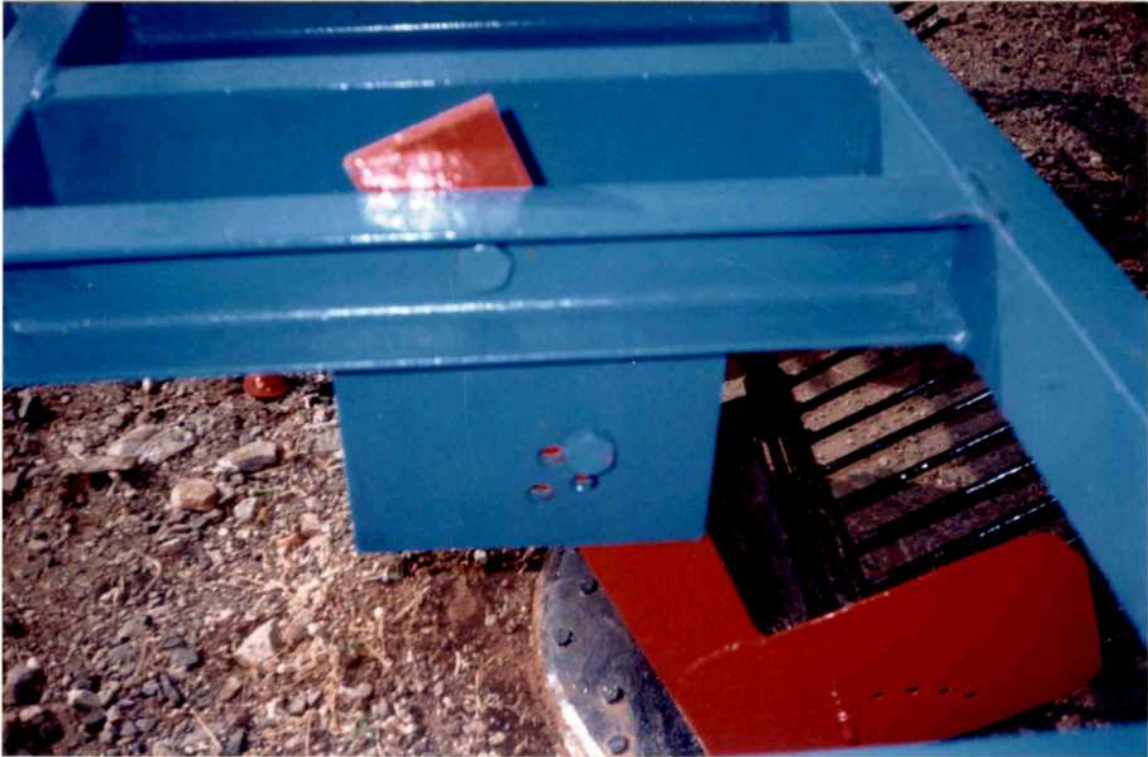


Plate 3.11. Bracket on the main frame to mount the shank with holes to set the rake angle



Plate 3.12. Adjustment of lift rod angle



Plate 3.13. Measurement of draft for tractor mounted with turmeric harvester pulled by another tractor



Plate 3.14. Measurement of draft with load cell instrumentation

Table 3.2. The affected response variables were harvesting efficiency, draft and percentage of damaged rhizomes.

3.8. Fabrication of prototype turmeric harvester

A prototype to harvest turmeric as explained in Sec. 3.5. was fabricated with the following components and the design parameters optimised in the experiment (Fig 3.5, 3.6, 3.7 and 3.8).

1. Main frame
2. Digger blade
3. Lift rod
4. Shank

3.9. Field performance evaluation of the prototype harvester

The prototype tractor drawn turmeric harvester was tested for harvesting three varieties namely Erode, Salem and BSR-1, in clay loam and sandy loam soils. The engine speed of the tractor was kept constant at 1600 rpm throughout the tests and forward speed of approximately 2.5 kph was obtained by selecting appropriate transmission ratio. The various tool parameters were set at the levels optimised by experimentation discussed in Sec. 3.7.1. Observations were made for three replications and the data were recorded. The harvester was operated in an area of 0.5 ha for each test and the evaluation was carried out by following the procedure described by RNAM (Anon, 1983). The performance of the tractor drawn turmeric harvester was evaluated in terms of harvesting efficiency, draft, field capacity, field efficiency and damage caused to the rhizomes.

S.No	DESCRIPTION
1	HITCH FRAME
2	MAIN FRAME
3	MOUNTING BRACKET
4	SHANK
5	LIFT ROD
6	BLADE
7	SIDE SHIELD
8	LIFT ROD ANGLE ADJUSTMENT

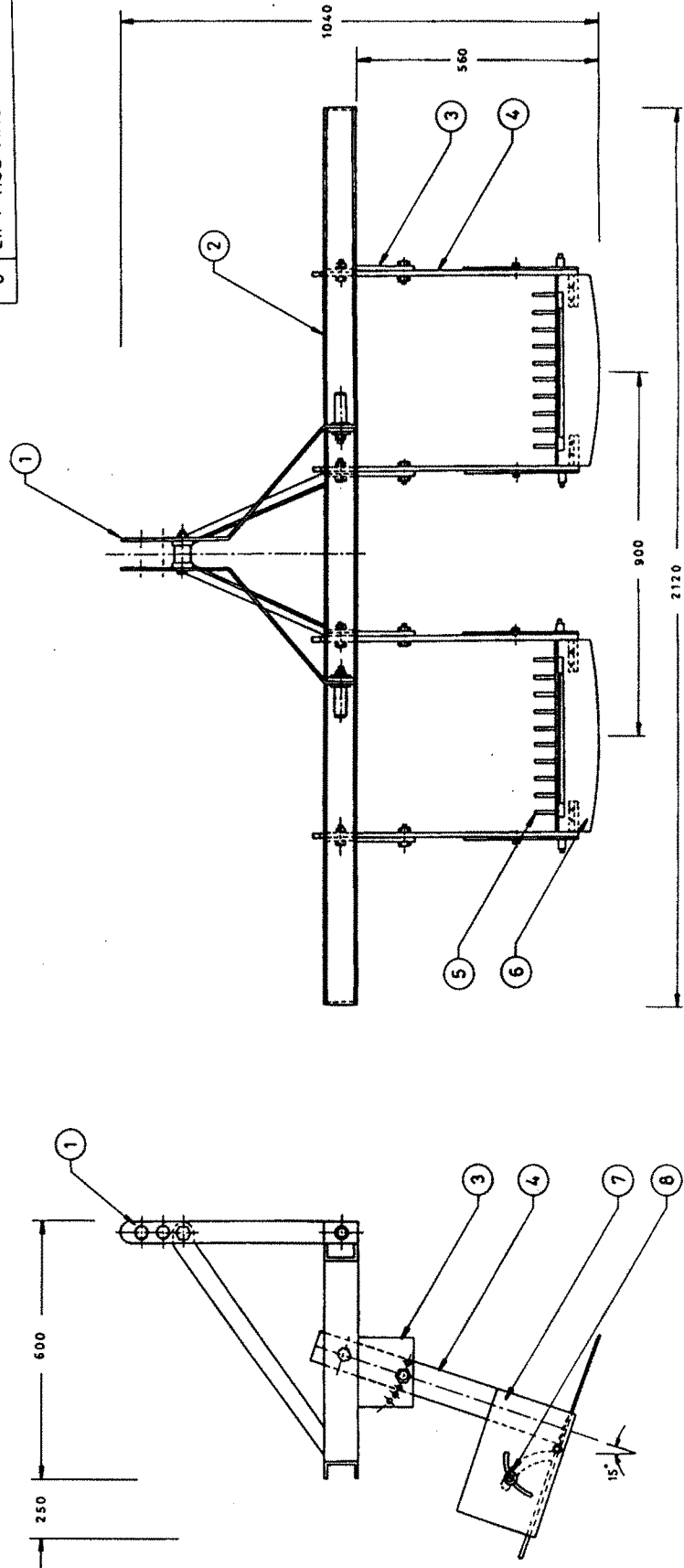


Fig.3.5. TRACTOR DRAWN TURMERIC HARVESTER MAT : M.S. SCALE - 1 : 10

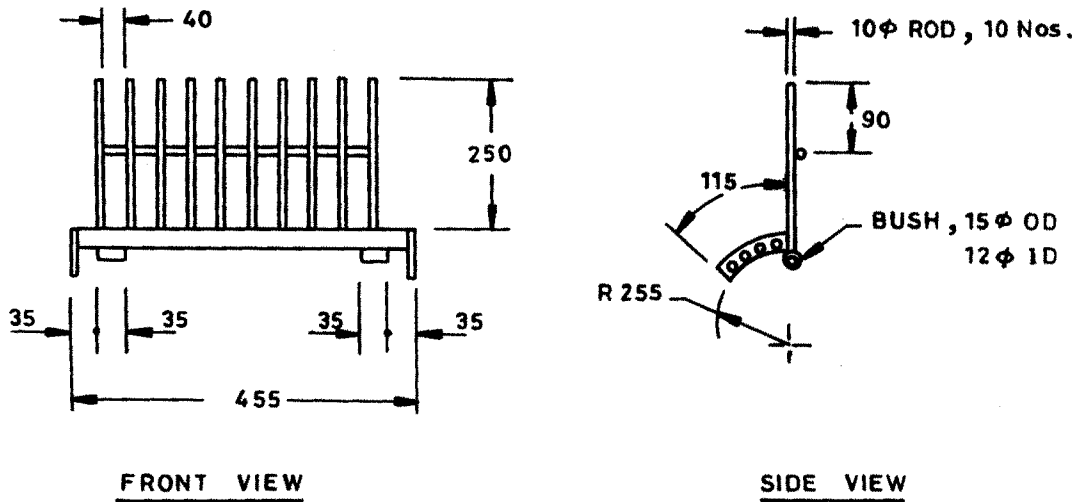


Fig.3.6. LIFT ROD ASSEMBLY

MAT : M.S.

SCALE - 1:10

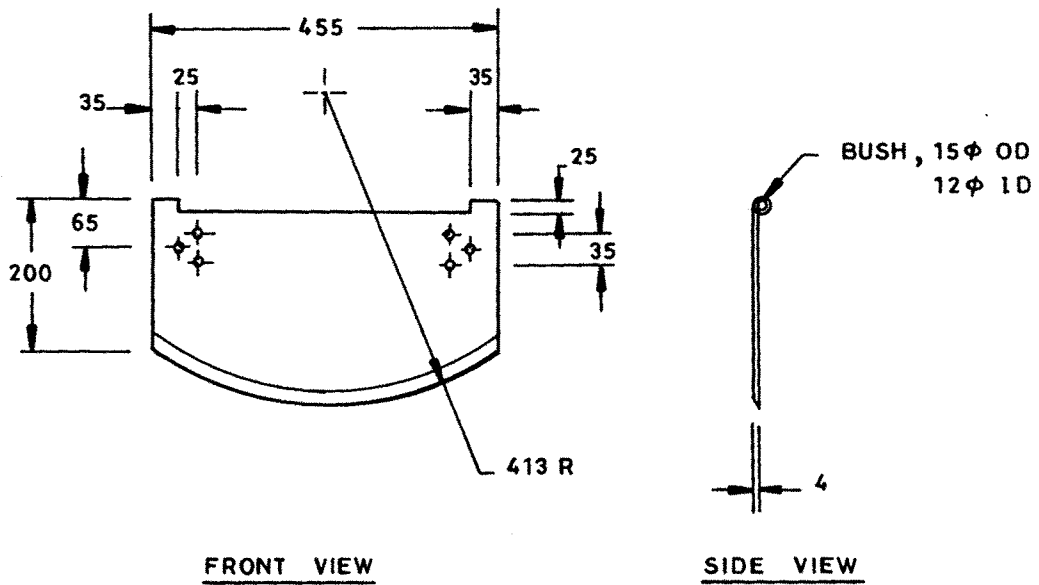


Fig.3.7. BLADE MAT : M.S. SCALE - 1:10

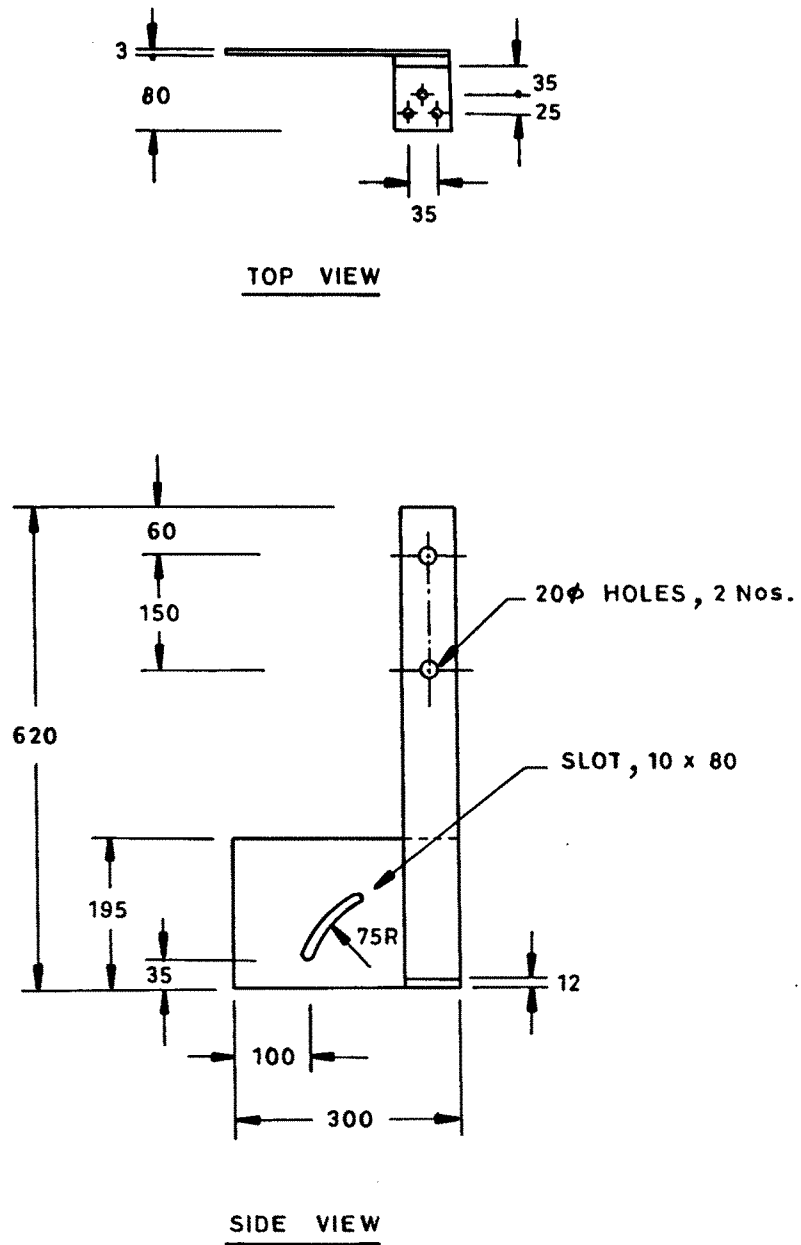


Fig.3.8. SHANK WITH SIDE SHIELD

MAT : M.S.

SCALE - 1 : 10

3.10. Cost economics

The total cost of the turmeric harvester was calculated. The fixed and variable costs for operating the machine per hour were calculated as per the procedure enumerated by RNAM (Anon., 1983). The cost of operation per ha was worked out. The performance was compared with conventional method of harvesting, in terms of savings in cost and improvement in harvesting efficiency. The break even point (BEP) and pay back period of the harvester were also worked out.

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

The various studies on conventional method of harvesting turmeric and its associated aspects, the soil, crop and tool parameters in relation to mechanical harvesting; and field evaluation performance studies on prototype harvester developed are discussed and the results are presented and discussed in this chapter.

4.1. Conventional method of harvesting

The data and information collected on conventional method of harvesting were analysed for area coverage and cost of harvesting. The labour required for harvesting one ha of turmeric was 28 man-days (digging only) and for picking the harvested rhizome. 131 women days per ha was required. The harvesting efficiency was about 87.93 per cent. The damage caused to the rhizome by digging with fork was 8.21 per cent. The average cost of harvesting and picking worked out to Rs.7480 at the wage rate of Rs.80 and Rs.40 per day for skilled labour and women labour respectively.

4.2. Soil parameters

The soil parameters analysed experimentally in the study were soil type, soil moisture, bulk density and cone index. The properties were determined at the time of harvest.

4.2.1. Soil type

The typical soils, where the experiments were conducted, were analysed for their textural composition. The soil samples taken from Thondamuthur had 26.3, 32.3

and 41.4 per cent, sand, silt and clay respectively which was classified as typical clay loam soil and the soil samples from Bhavanisgar had 66.3, 22.3 and 11.4 per cent sand, silt and clay respectively which was classified as sandy loam.

4.2.2. Soil moisture

The moisture content of soil at the time of harvest was determined as explained in Sec. 3.3.2. The optimum soil moisture content required for mechanical harvesting was studied by harvesting the crop at different soil moisture contents namely at 3, 7 and 12 days after irrigation for both sandy loam and clay loam soils, with respect to draft and harvesting efficiency. The soil moisture data collected is given in Annexure-I. The results are presented in Table 4.1.

Table 4.1. Soil moisture at different periods after irrigation

Soil type Harvesting day after irrigation	Sandy loam			Clay loam		
	3	7	12	3	7	12
a) Moisture content dry basis - per cent						
Statistical parameter						
Maximum	15.30	10.05	8.91	24.80	16.70	12.86
Minimum	14.01	9.21	7.70	22.98	15.01	11.20
Mean	14.67	9.70	8.31	23.97	15.98	11.83
b) Draft - kg						
Statistical parameter						
Maximum	380	320	310	425	343	330
Minimum	330	270	260	340	301	240
Mean	340	295	280	380	325	310
c) Harvesting efficiency - per cent						
Statistical parameter						
Maximum	98.5	98.5	96.0	97.0	98.0	93.0
Minimum	93.0	94.0	91.0	92.0	93.0	90.0
Mean	96.0	97.0	93.0	95.0	96.5	91.5

The mean soil moisture content in sandy loam at harvest were 14.69, 9.70 and 8.31 per cent respectively, after 3, 7 and 12 days of irrigation prior to harvest, while in clay loam soil the corresponding values were 23.97, 15.98 and 11.83 per cent respectively.

The draft of the experimental tool was minimum when harvested after 12 days of irrigation while the harvesting efficiency was maximum after 7 days of irrigation in both the types of soil. The maximum harvesting efficiency of 98.5 and 98.0 per cent were recorded when harvested after 7 days of irrigation in sandy loam soil at the mean soil moisture level of 9.7 per cent and in clay loam soil at mean soil moisture level of 15.98 per cent respectively. This indicated that for mechanical harvesting, the optimum moisture content for maximum harvesting efficiency could be obtained probably after 7 days of irrigation in both the types of soil. Fig.4.1. illustrates the performance of the mechanical harvester at different soil moisture levels. Since the draft requirement was higher in clay loam soil than the sandy loam soil, the study on optimising the tool parameters was confined to the clay loam soil.

4.2.3. Bulk density

The details of bulk density of soil in both fields determined as described in Sec. 3.3.3, are given in Annexure-II and the analysed data are furnished in Table 4.2.

Table 4.2. Bulk density of soils

Statistical parameter	Bulk density (g cm ⁻³)	
	Sandy loam	Clay loam
Maximum	1.52	1.66
Minimum	1.40	1.56
Mean	1.466	1.563

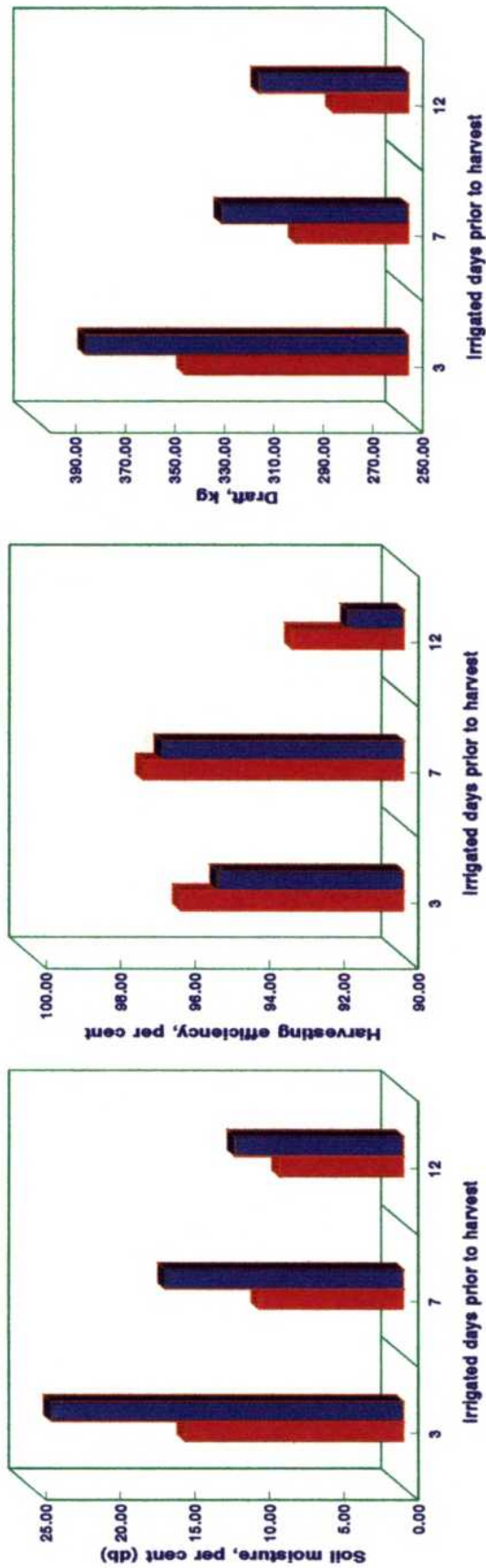


Fig.4.1 Soil moisture levels at different periods of harvest after irrigation and their influence on harvester performance

From Table 4.2. it is seen that the mean bulk density was observed as 1.466 and 1.563 g cm⁻³ respectively for sandy loam and clay loam soils.

4.2.4. Cone index

The soil cone index at the time of turmeric harvest was measured as described in Sec. 3.3.4. The data are given in Annexure-III and the results are furnished in Table 4.3.

Table 4.3. Cone index of clay loam soil

Soil moisture Depth - cm	Cone index (kg cm ⁻²)								
	24.0 (%)			16.0 (%)			9-10 (%)		
	0-10	10-15	15-20	0-10	10-15	15-20	0-10	10-15	15-20
Statistical parameter									
Maximum	1.70	3.60	5.10	2.00	4.00	5.40	2.55	4.25	5.80
Minimum	1.35	3.45	4.65	1.75	3.85	5.15	2.35	4.10	5.60
Mean	1.50	3.51	4.69	1.86	3.89	5.31	2.41	4.19	5.70

The mean values of cone index of the clay loam soil were 1.50, 1.86 and 2.41 kg cm⁻² at 0-10 cm soil depth, 3.51, 3.89 and 4.19 kg cm⁻² at 10-15 cm soil depth and 4.69, 5.31 and 5.70 kg cm⁻² at 15-20 cm soil depth at the soil moisture levels 24, 16 and 12 per cent respectively. The soil cone index increased with decrease in soil moisture and increase in soil depth. This variation in cone index is illustrated in Fig.4.2. The resistance of the soil to penetration by the tool decreases with moisture content of soil but considering the higher draft required at higher moisture levels, an optimum moisture level has to be chosen where the draft required as well as the soil penetration resistance will be moderate and within working limits for obtaining maximum harvesting efficiency. Therefore harvesting at about 16 per cent soil moisture level for clay loam soil is probably the suitable field condition for obtaining maximum harvesting

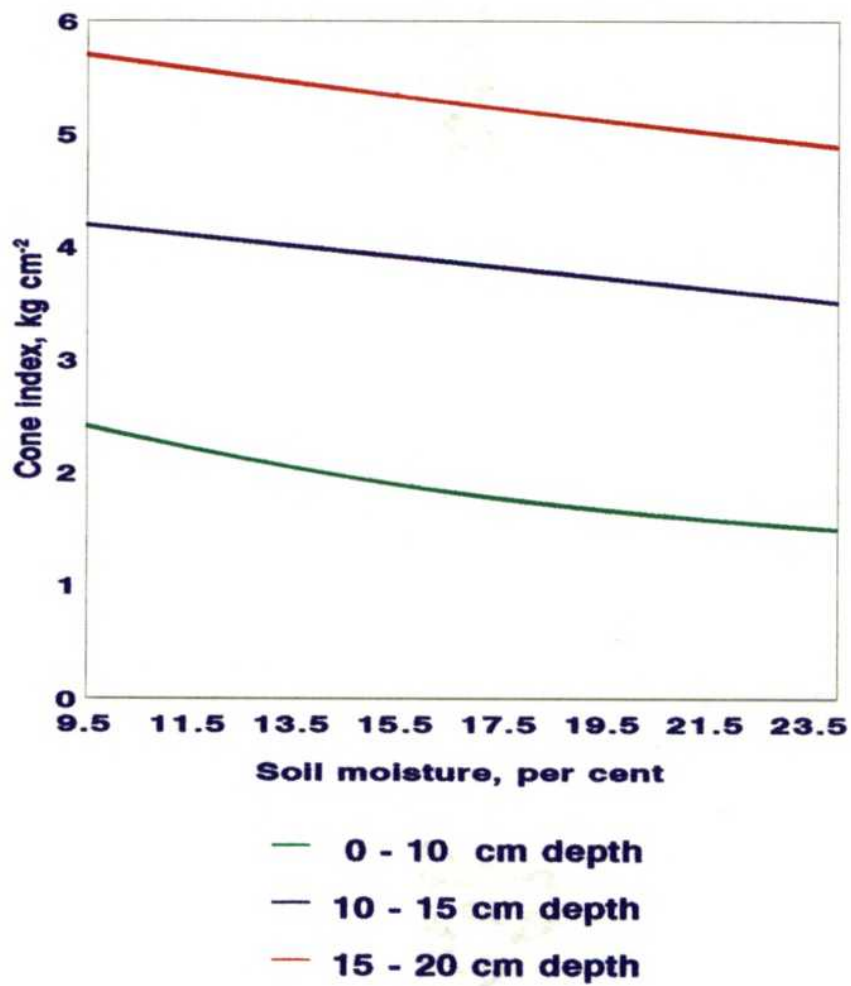


Fig.4.2. Cone index at different soil depths and soil moisture levels

efficiency by mechanical means and hence the tests for the performance of tool variables for mechanical harvesting were conducted at this soil moisture level.

4.3. Crop parameters

The crop parameters influencing the mechanical harvesting of turmeric were identified as plant population, rhizome spread (vertically and laterally), rhizome weight, number of fingers per rhizome, moisture content and bulk density of rhizomes. The determination of these parameters are discussed in this section.

4.3.1. Plant population

The plant population per square metre for the three varieties of turmeric was counted and the details are given in Annexure-IV. The data were statistically analysed and summarized in Table 4.4.

Table 4.4. Plant population

Statistical inference Crop variety	Population per square metre		
	Erode	Salem	BSR-1
Statistical parameter			
Maximum	13.00	12.00	9.00
Minimum	11.80	11.00	8.00
Mean	12.55	11.46	8.53

The mean plant population per square metre was 12.55, 11.46 and 8.53 for Erode, Salem and BSR-1 varieties respectively. The lower population for BSR-1 variety was due to the adoption of wider spacing of 60 x 20 cm.

4.3.2. Rhizome spread

The spread of turmeric rhizome laterally and vertically in the soil was measured as explained in Sec. 3.4.3 and the data is furnished in Annexure V. The statistical information is given in Table 4.5.

Table 4.5. Rhizome spread of turmeric crop varieties

Statistical parameter	Variety					
	Erode		Salem		BSR-1	
	Lateral Spread - b (mm)	Vertical spread - d (mm)	Lateral Spread - b (mm)	Vertical spread - d (mm)	Lateral Spread - b (mm)	Vertical spread - d (mm)
Maximum	260.0	185.0	270.0	200.0	300.0	170.0
Minimum	240.0	160.0	240.0	185.0	270.0	155.0
Mean	240.0	176.0	255.0	192.0	283.0	162.5

The maximum rhizome spread laterally was 260, 270 and 300 mm for Erode, Salem and BSR-1 varieties respectively and the corresponding vertical spread were 185, 200 and 170 mm respectively.

The average values were 240, 255 and 283 mm for lateral spread and 176, 192 and 162.5 mm for vertical spread for Erode, Salem and BSR-1 varieties respectively. The rhizome spread is illustrated in Fig.3.1. in Sec. 3.4.3. Hence the depth of operation of the digging tool was fixed at 200 mm. The designed length of the blade, namely 450 mm was sufficient to digout all the rhizomes spread laterally without damage.

4.3.3. Rhizome weight

The rhizome weight with the soil is an important parameter in the design of lift rods of the digger blade since the rhizomes dugout by the blade has to be lifted up and dropped back. The recorded observation on the weight of rhizomes of different

varieties are given in Annexure-VI and the statistically analysed data are given in Table 4.6.

Table 4.6. Weight of turmeric rhizome at the time of harvest

Statistical parameter	Variety					
	Erode		Salem		BSR-1	
	With soil (g)	Without soil (g)	With soil (g)	Without soil (g)	With soil (g)	Without soil (g)
Maximum	700	240	800	280	480	310
Minimum	630	210	700	240	440	280
Mean	654	225	757	261	457	296

The average weight of each clump with soil was 654, 757 and 457 g for Erode, Salem and BSR-1 varieties respectively. More soil was found to adhere to the rhizomes in clay loam than in sandy loam soil. The range of weights of rhizome (without soil) was 210 to 240, 240 to 280 and 280 to 290 g for the above respective varieties.

4.3.4. Moisture content of rhizome

The moisture content of rhizomes at the time of harvest is an important parameter in handling of the crop while digging it out from soil. The moisture content was determined as explained in Sec. 3.4.5, and tabulated in Annexure-VII and the data are presented in Table 4.7.

Table 4.7. Moisture content of rhizome at harvest

Statistical parameter	Variety		
	Erode per cent (db)	Salem per cent (db)	BSR-1 per cent (db)
Maximum	75.6	77.3	72.1
Minimum	71.0	74.6	70.1
Mean	73.8	75.6	71.0

Since the moisture content of rhizomes at the time of harvest is very high, the soil has a tendency to adhere to the rhizome and it comes out along with the soil adding to the weight of the crop to be handled by the machine.

4.3.5. Number of fingers per hill

The number of fingers per hill is also an important parameter as it determines the volume of crop to be handled by the machine. The data on number of fingers counted from 10 hills of each variety is given in Annexure-VIII and the Table 4.8. shows the analysed data.

Table 4.8. Number of fingers per hill

Statistical parameter	Variety								
	Erode			Salem			BSR-1		
	mother rhizome	primary finger	sec. finger	mother rhizome	primary finger	sec. finger	mother rhizome	primary finger	sec. finger
Maximum	2	9	17	2	6	13	3	10	20
Minimum	2	7	14	1	5	9	2	8	15
Mean	2.0	7.7	14.8	1.6	5.7	11.7	2.4	9.0	17.5

From Table 4.8, it can be seen that BSR-1 variety had maximum number of fingers and Erode variety had more number of fingers than Salem variety indicating that the volume to be handled will be more in BSR-1 variety. The number of fingers will also give an indication about the bulk density of the harvested produce which is explained in Sec. 4.3.6.

4.3.6. Bulk density of rhizome

The data on bulk density measured as explained in Sec.3.4.7 for three varieties are given in Annexure-IX and Table 4.9.

Table 4.9. Bulk density of rhizomes at harvest

Statistical parameter	Variety		
	Erode (kg m ⁻³)	Salem (kg m ⁻³)	BSR-1 (kg m ⁻³)
Maximum	1001.00	1160.00	1180.00
Minimum	968.00	1078.00	1150.00
Mean	984.60	1126.60	1168.40

The data in Table 4.9 show that bulk density of Erode variety was less than that of Salem and BSR-1 varieties. The mean values of bulk density were 984.6, 1126.6 and 1168.4 kg per m³ for Erode, Salem and BSR-1 varieties respectively.

4.4. Tool and operational parameters

The main tool parameters, namely tool geometry, width, length, rake angle and lift rod angle and length; and operational parameters such as speed of operation and depth were studied. The levels of the tool parameters were optimised by experimentation. The digging tool with provisions for adjustments for different levels of independent variables was mounted in the frame hitched to the three point link of a 35 hp tractor. Necessary instrumentation was adopted for measuring draft of the tool. The effects of tool parameter variables were evaluated in relation to harvesting efficiency, draft requirement and damage caused to harvested rhizomes, at the optimised soil moisture level.

4.4.1. Effect of tool parameters

4.4.1.1. Analysis of variance for harvesting efficiency

The performance of the tools for harvesting Erode variety of turmeric crop was evaluated to assess the harvesting efficiency of the tool by varying the factors at different levels as given in Table 3.2. The results obtained for the analysis of variance for harvesting efficiency are given in Table 4.10.

Table 4.10. Analysis of variance for harvesting efficiency

SV	DF	SS	MS	F
Treatment	80	1255.079	15.688	114.48 **
Lift rod angle (M)	2	15.804	7.902	57.67 **
Lift rod length (L)	2	3.840	1.920	14.01 **
Rake angle (A)	2	809.891	404.945	2955.01 **
Tool shape (T)	2	367.109	183.554	1339.45 **
M x L	4	1.293	0.323	2.36 ns
M x A	4	0.272	0.068	<1
M x T	4	2.969	0.742	5.42 **
L x A	4	3.726	0.931	6.80 **
L x T	4	3.832	0.958	6.99 **
A x T	4	25.746	6.436	46.97 **
M x L x A	8	3.292	0.411	3.00 **
M x L x T	8	3.637	0.454	3.32 **
M x A x T	8	2.845	0.355	2.60 *
L x A x T	8	6.277	0.784	5.73 **
M x L x A x T	16	4.540	0.283	2.07 *
Error	162	22.200	0.137	
Total	242	1277.279		

cv - 0.4 %

** - significant at 1% level; * - significant at 5% level

ns - not significant

From Table 4.10, it is seen that the main effect of all the four factor (M, L, A, T) was significant indicating that each factor was individually influencing the harvesting efficiency. The interaction effects of M x T, L x A, L x T, A x T, M x L x A and

L x A x T were significant at 1 per cent level, while the interaction effects of M x A x T and M x L x T were significant at 5 per cent level. The interaction effects of M x L and M x A were not significant.

a) Effect of rake angle on harvesting efficiency

The main effect of rake angle significantly influenced the harvesting efficiency. Among the rake angles studied, 20 deg recorded the maximum harvesting efficiency of 94.38 per cent and was significantly superior to 15 and 25 deg. Between 15 and 25 deg rake angles, 25 deg recorded better harvesting efficiency.

The interaction effect of rake angle with different tool geometry, lift rod lengths and lift rod angles on harvesting efficiency are given in Table 4.11.

Table 4.11. Interaction effects of AxT, LxA and Mx A factors means on harvesting efficiency

AxT table of means for harvesting efficiency (per cent)

Tool shape (T)	Rake Angle (A)			T - mean
	15 deg	20 deg	25 deg	
Straight	90.15	93.76	93.16	92.36
Crescent	91.18	96.43	94.17	93.92
Inverted-V	88.59	92.94	91.21	90.91
A- mean	89.97	94.38	92.85	92.40

LxA table of means for harvesting efficiency (per cent)

Rake angle (A)	Lift rod length (L)			A - mean
	15 cm	25 cm	35 cm	
15 Deg	89.90	90.30	89.72	89.97
20 Deg	94.44	94.44	94.24	94.38
25 Deg	93.08	92.77	92.70	92.85
L - mean	92.47	92.50	92.22	92.40

MxA table of means for harvesting efficiency (per cent)

(Table 4.11. Contd..)

Rake angle (A)	Lift rod angle (M)			A - mean
	-5 deg	5 deg	15 deg	
15 Deg	89.94	90.26	89.71	89.97
20 Deg	94.36	94.70	94.07	94.38
25 Deg	92.90	93.17	92.48	92.85
M - mean	92.40	92.71	92.09	92.40

The interaction effects of L x A and A x T were significant and that of M x A was not significant indicating that while the harvesting efficiency at different rake angles was influenced by lift rod length and tool shape, no such influence was exerted by lift rod angle.

L x A table also shows a similar trend of the rake angle of 20 deg showing maximum harvesting efficiency at all levels of lift rod length.

M x A table of means for harvesting efficiency (Table 4.11) also shows that the rake angle of 20 deg gave maximum harvesting efficiency irrespective of lift rod angle. As the angle of lift rod was increased from -5 to 15 deg, the harvesting efficiency did not show any significant change at any of the rake angle levels showing non significant interaction between rake angle and lift rod angle.

The effects of rake angle on harvesting efficiency at different lift rod angles with various lift rod lengths for the different tool shapes are illustrated in Figs.4.3 to 4.5. As seen from the figures, 20 deg rake angle showed the highest harvesting efficiency at various lift rod angles and it was more pronounced in crescent and inverted-V shaped tools than in the straight blade tool.

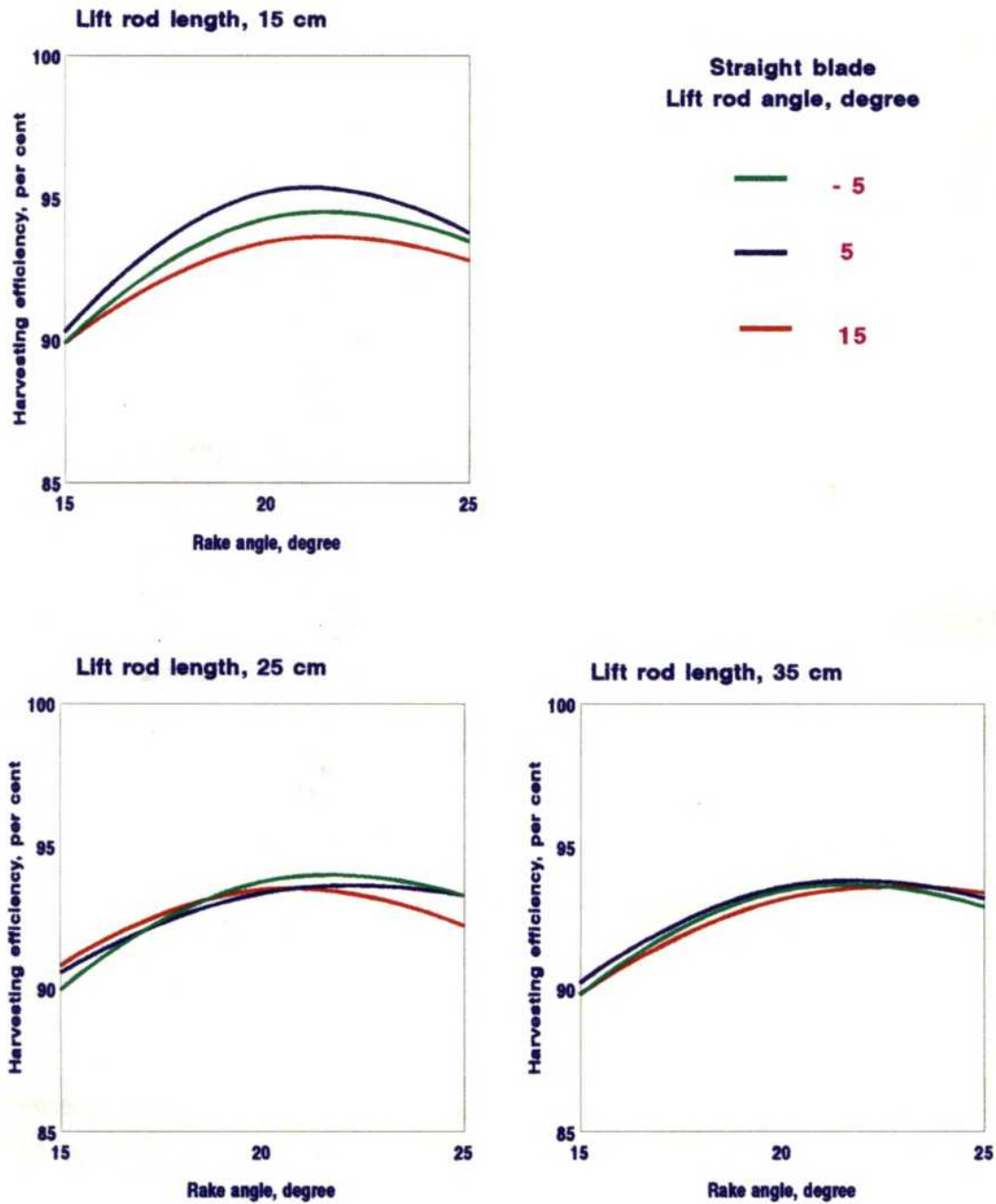


Fig.4.3. Effect of rake angle on harvesting efficiency at different lift rod angles

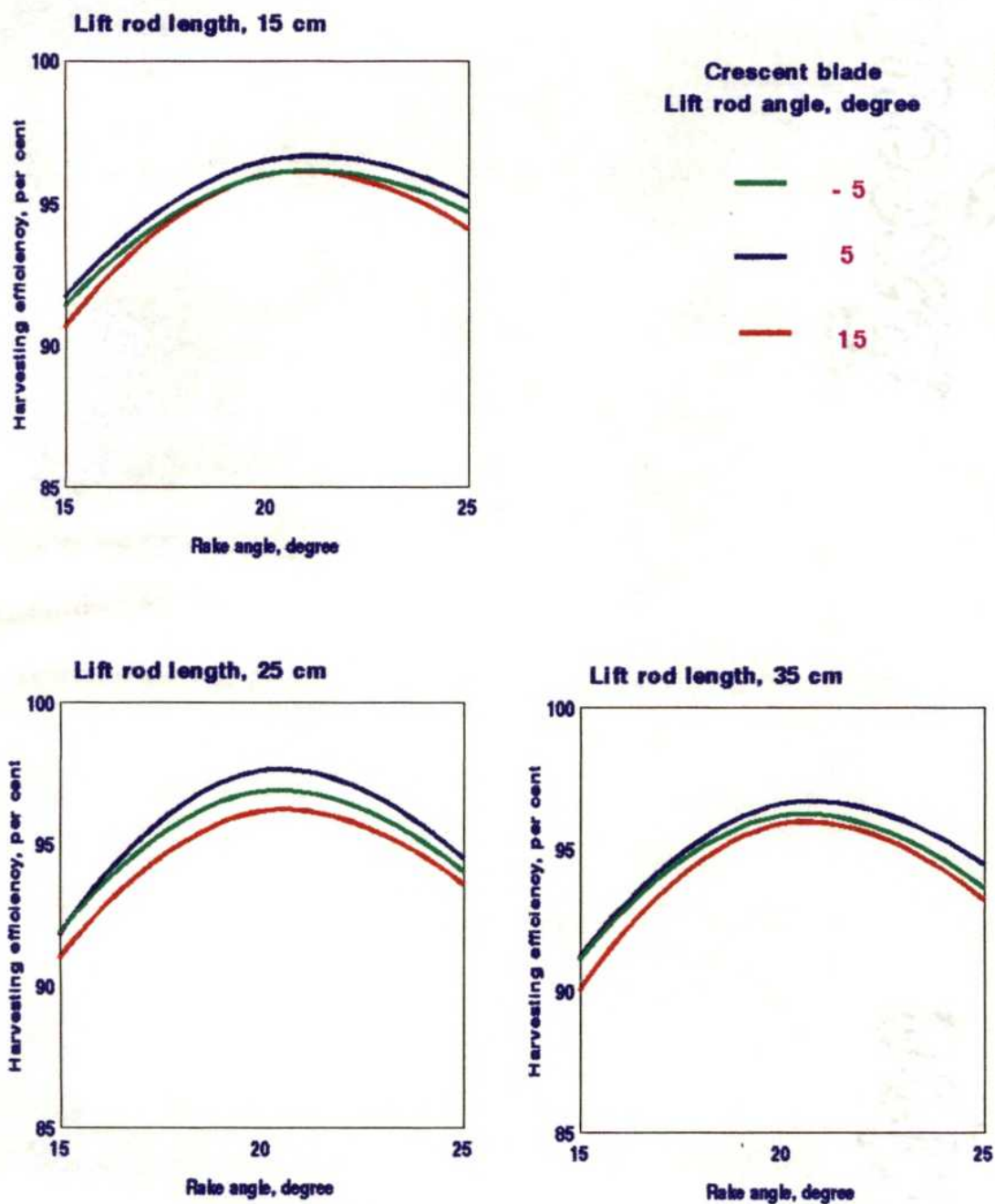


Fig.4.4. Effect of rake angle on harvesting efficiency at different lift rod angles

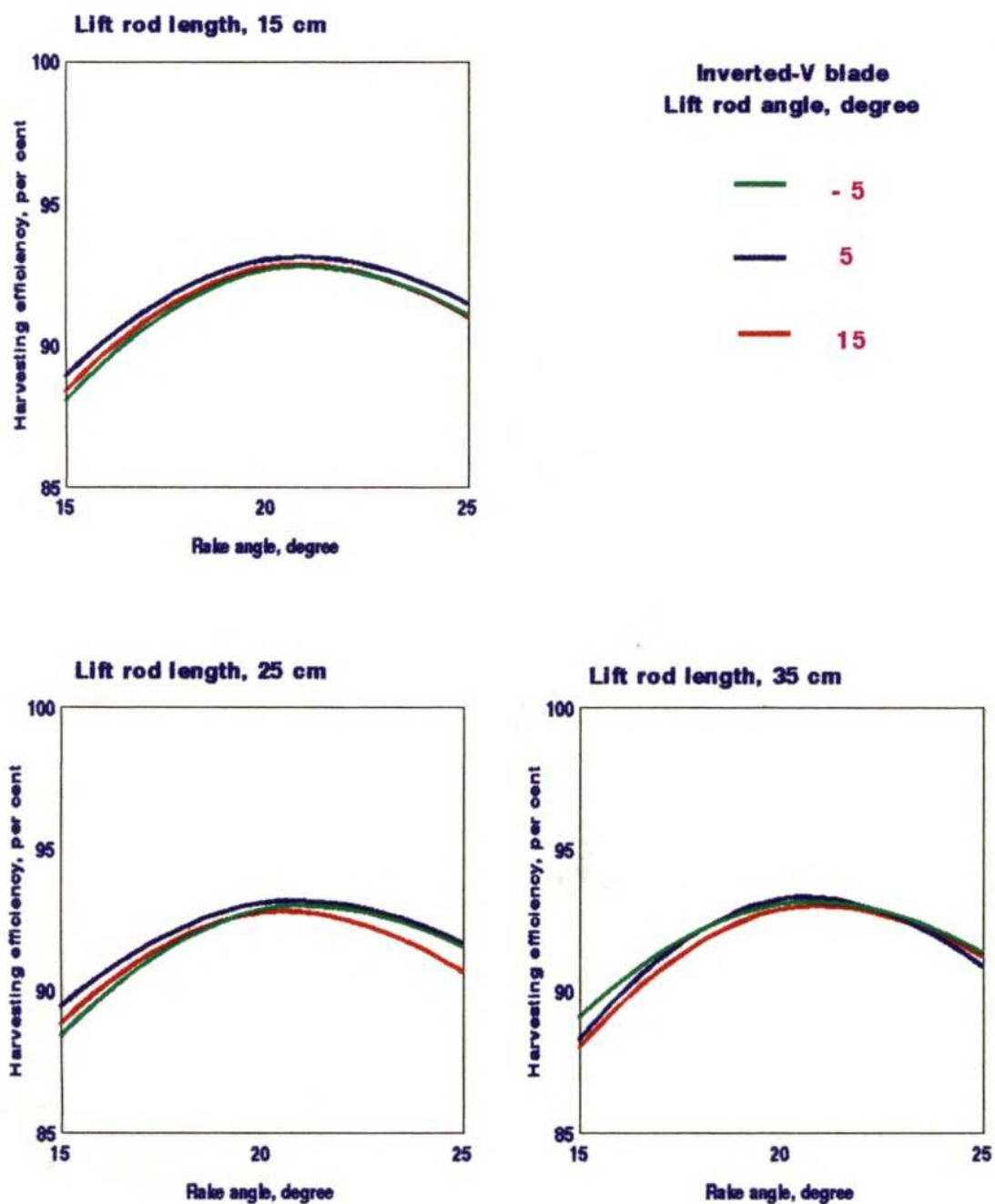


Fig.4.5. Effect of rake angle on harvesting efficiency at different lift rod angles

b) Effect of tool geometry on harvesting efficiency

The main effect of tool geometry shapes significantly influenced the harvesting efficiency. Of the three tool shapes studied, the crescent shaped tool gave maximum harvesting efficiency of 93.92 per cent, significantly better than straight and inverted-V shaped tools.

The interactive influence of tool geometry on harvesting efficiency of the tool at different levels of lift rod lengths and lift rod angles are given in Table 4.12. The interaction effects of L x T and M xT were significant implying that the harvesting efficiency for different tool shapes was influenced by lift rod length and lift rod angle.

Table 4.12. Interaction effects of LxT and MxT factors means on harvesting efficiency

LxT table of means for harvesting efficiency (per cent)

Tool shape (T)	Lift rod length (L)			T - mean
	15 cm	25 cm	35 cm	
Straight	92.58	92.31	92.18	92.36
Crescent	94.03	94.16	93.59	93.92
Inverted-V	90.81	91.04	90.90	90.91
L- mean	92.47	92.50	92.22	92.40

MxT table of means for harvesting efficiency (per cent)

Tool shape (T)	Lift rod angle (M)			T - mean
	-5 Deg	5 Deg	15 Deg	
Straight	92.32	92.62	92.13	92.36
Crescent	93.97	94.40	93.40	93.92
Inverted-V	90.90	91.11	90.73	90.91
M - mean	92.40	92.71	92.09	92.40

From Table 4.11 for A x T, it is seen that the increase in rake angle increased the harvesting efficiency initially upto 20 deg and subsequently decreased the harvesting efficiency in all the three shapes of tool geometry. The maximum harvesting

efficiency was achieved at 20 deg rake angle in all the three shapes of tool geometry and among all three tool shapes, the crescent shaped tool achieved maximum harvesting efficiency of 96.43 per cent at 20 deg rake angle.

Lx T and M x T tables of means (Table 4.12) indicate that the crescent shaped blade performed best and the inverted-V shaped tool performed least in terms of harvesting efficiency at all levels of lift rod length and lift rod angle.

c) Effect of lift rod length on harvesting efficiency

The main effect of lift rod length significantly influenced the harvesting efficiency with the lift rod length of 250 mm showing the highest efficiency.

The interaction effects of lift rod length on harvesting efficiency of the tool with different lift rod angles and different tool geometry shapes are given in Tables 4.11 and 4.12. It is observed that the increase in lift rod angle did not give significant interactive effect on harvesting efficiency with the lift rod length which is clearly illustrated in Figs. 4.3 to 4.5. All the lift rod lengths had significant interactive influence on harvesting efficiency with different tool geometry shapes, specifically the crescent shaped tool performing the best at 250 mm lift rod length.

d) Effect of lift rod angle on harvesting efficiency

The main effect of lift rod angle significantly influenced the harvesting efficiency with 5 deg angle showing the highest efficiency.

The interaction effects of lift rod angle with tool shapes had significant influence with the 5 deg lift rod angle having the highest harvesting efficiency in crescent shaped tool.

e) Combined effect of rake angle, lift rod length and lift rod angle on harvesting efficiency

Table 4.13. Combined effect of rake angle, lift rod length and lift rod angle on harvesting efficiency - MxLxA table of means

Rake angle (A)	Lift rod angle (M)			A - mean
	-5 deg	5 deg	15 deg	
L = 15 cm				
15 Deg	89.77	90.30	89.63	89.90
20 Deg	94.32	94.69	94.08	94.44
25 Deg	93.09	93.50	92.64	93.08
L = 25 cm				
15 Deg	90.08	90.60	90.21	90.30
20 Deg	94.50	94.92	94.14	94.44
25 Deg	92.97	93.17	92.17	92.77
L = 35 cm				
15 Deg	89.99	89.89	89.29	89.72
20 Deg	94.26	94.49	93.99	94.24
25 Deg	92.63	92.84	92.62	92.70
M - mean	92.40	92.71	92.09	92.40

Table 4.13 shows the M x L x A combined effect on harvesting efficiency. It is observed that the change in rake angle had significant effect on harvesting efficiency at all combinations of rake angle, lift rod angle and lift rod length. The maximum harvesting efficiency of 94.92 per cent was achieved at 20 deg rake angle, 250 mm lift rod length and 5 deg lift rod angle.

The lowest harvesting efficiency was 89.29 per cent recorded at 15 deg rake angle, 350 mm lift rod length and 15 deg lift rod angle. This analysis of the means of the combined effects of M x L x A indicates 20 deg rake angle, 250 mm lift rod length and 5 deg lift rod angle as the best combination of the tool parameters considered for any shape of tool.

f) Multiple linear regression analysis for harvesting efficiency

The statistical technique of multiple linear regression analysis was carried out with harvesting efficiency as dependent variable and, rake angle, lift rod length and lift rod angle as independent variables separately for all the tool shapes.

The regression equations arrived for harvesting efficiency for turmeric are (Annexure X to XII),

For straight tool,

$$Y = 86.881 - 0.01 (X_1) - 0.02 (X_2) + 0.3 (X_3)$$

For crescent tool

$$Y = 88.639 - 0.03 (X_1) - 0.02 (X_2) + 0.3 (X_3) \text{ and}$$

For inverted-V tool,

$$Y = 85.601 - 0.01 (X_1) + 0.004 (X_2) + 0.3 (X_3).$$

where,

Y	=	Harvesting efficiency, per cent
X ₁	=	Lift rod angle, deg
X ₂	=	Lift rod length, mm
X ₃	=	Rake angle, deg

The regression coefficient R² values were 0.51, 0.73 and 0.76 respectively which indicated that 51, 73 and 76 per cent of the variations in harvesting efficiency with straight, crescent and inverted V shaped tools were influenced by the other three parameters considered. All these R² values were significant at 1 per cent level indicating that the selected variables were significant to predict the harvesting efficiency. The regression equations in all the three shapes indicated positive correlation

with rake angle and negative correlation with lift rod angle and lift rod length in the case of straight and crescent shaped blades but negative correlation with lift rod angle and positive correlation with lift rod length and rake angle for inverted V shaped tool. However the effects of lift rod angle and lift rod length on harvesting efficiency were only marginal in all the three tools. The effect of rake angle on harvesting efficiency was positively expressed in all the tools.

4.4.1.2. Analysis of variance for draft

The performance of the harvesting tool blades for Erode variety of turmeric was evaluated to assess draft requirement by varying the factors at different levels as given in Table 3.2. and the results obtained for analysis of variance are given in Table 4.14.

Table 4.14. Analysis of variance for draft

SV	DF	SS	MS	F
Treatment	80	853053.22	10663.17	775.79 **
Lift rod angle (M)	2	51598.03	25799.02	1876.99 **
Lift rod length (L)	2	83703.91	41851.95	3044.92 **
Rake angle (A)	2	180577.93	90288.97	6568.93 **
Tool shape (T)	2	511129.39	255564.70	18593.48 **
M x L	4	138.24	34.56	2.51 *
M x A	4	174.88	43.72	3.18 *
M x T	4	511.13	127.78	9.30 **
L x A	4	4352.26	1088.07	79.16 **
L x T	4	861.47	215.37	15.67 **
A x T	4	11773.37	2943.34	214.14 **
M x L x A	8	653.96	81.74	5.95 **
M x L x T	8	725.27	90.66	6.60 **
M x A x T	8	587.14	73.39	5.34 **
L x A x T	8	4246.21	530.78	38.62 **
M x L x A x T	16	2020.02	126.25	9.19 **
Error	162	2226.67	13.74	
Total	242	855279.88		

cv - 1.1 %

** - significant at 1% level;

* - significant at 5% level

From table, it is seen that main effects of each factor namely rake angle (A), lift rod length (L), lift rod angle (M) and tool shape (A) were highly significant at 1 per cent level indicating that each factor was individually influencing the draft (Chase, 1942, Payne and Tanner, 1959). The interaction effects A x T, L x A, L x T, M x T, L x A x T, M x L x A, M x L x T, M x A x T and combined effect of M x L x A x T were significant at 1 per cent level while the interaction effects M x L and M x A were significant at 5 per cent level.

a) Effect of rake angle on draft

The main effects of rake angle had significant impact on draft. 15 deg rake angle required a draft of 306.80 kg compared to 351.40 and 372.10 kg for 20 and 25 deg rake angles respectively. The draft was found to increase with rake angle.

The interaction effects of rake angle with tool geometry, lift rod length and lift rod angle on draft are explained in Table 4.15. The interaction effects of A x T, L x A and M x A were significant revealing that the draft at different rake angles was influenced by tool geometry shape, lift rod angle and lift rod length.

Table 4.15. Interaction effects of AxT, LxA and Mx A factors means on draft

AxT table of means for draft (kg)

Tool shape (T)	Rake Angle (A)			T - mean
	15 deg	20 deg	25 deg	
Straight	357.0	422.3	437.6	405.6
Crescent	292.3	334.3	358.5	328.4
Inverted-V	271.1	297.5	320.3	296.3
A- mean	306.8	351.4	372.1	343.4

LxA table of means for draft (kg)**(Table 4.15 contd..)**

Rake angle (A)	Lift rod length (L)			A - mean
	15 cm	25 cm	35 cm	
15 Deg	276.6	310.2	333.6	306.8
20 Deg	330.7	349.5	373.9	351.4
25 Deg	356.3	367.7	392.4	372.1
L - mean	321.2	342.5	366.6	343.4

MxA table of means for draft (kg)

Rake angle (A)	Lift rod angle (M)			A - mean
	-5 deg	5 deg	15 deg	
15 Deg	290.3	304.4	325.7	306.8
20 Deg	336.5	347.2	370.4	351.4
25 Deg	356.7	367.1	392.6	372.1
M - mean	327.8	339.6	362.9	343.4

It is seen in Table 4.15 that increase in rake angle increased the draft of the tool in all the three shapes, at all lift rod lengths and lift rod angles. The interaction between the tool geometry and rake angle had a significant effect on draft. This is due to increase in soil resistance as the increase in rake angle increased the soil contact area (Harrison, 1982). This increasing trend in draft with increase in rake angle is illustrated in Figs. 4.6 to 4.8.

The draft was maximum for straight blade tool at 25deg rake angle and minimum for inverted V shaped tool at 15deg rake angle. It can be also seen from Figs. 4.6 to 4.8 that the minimum draft of 227.7 kg was experienced at 15 deg rake angle, 5 deg lift rod angle and 150 mm lift rod length in the inverted V shaped tool while the maximum draft of 474 kg was on straight blade at 25 deg rake angle, 350 mm lift rod length and 15 deg lift rod angle.

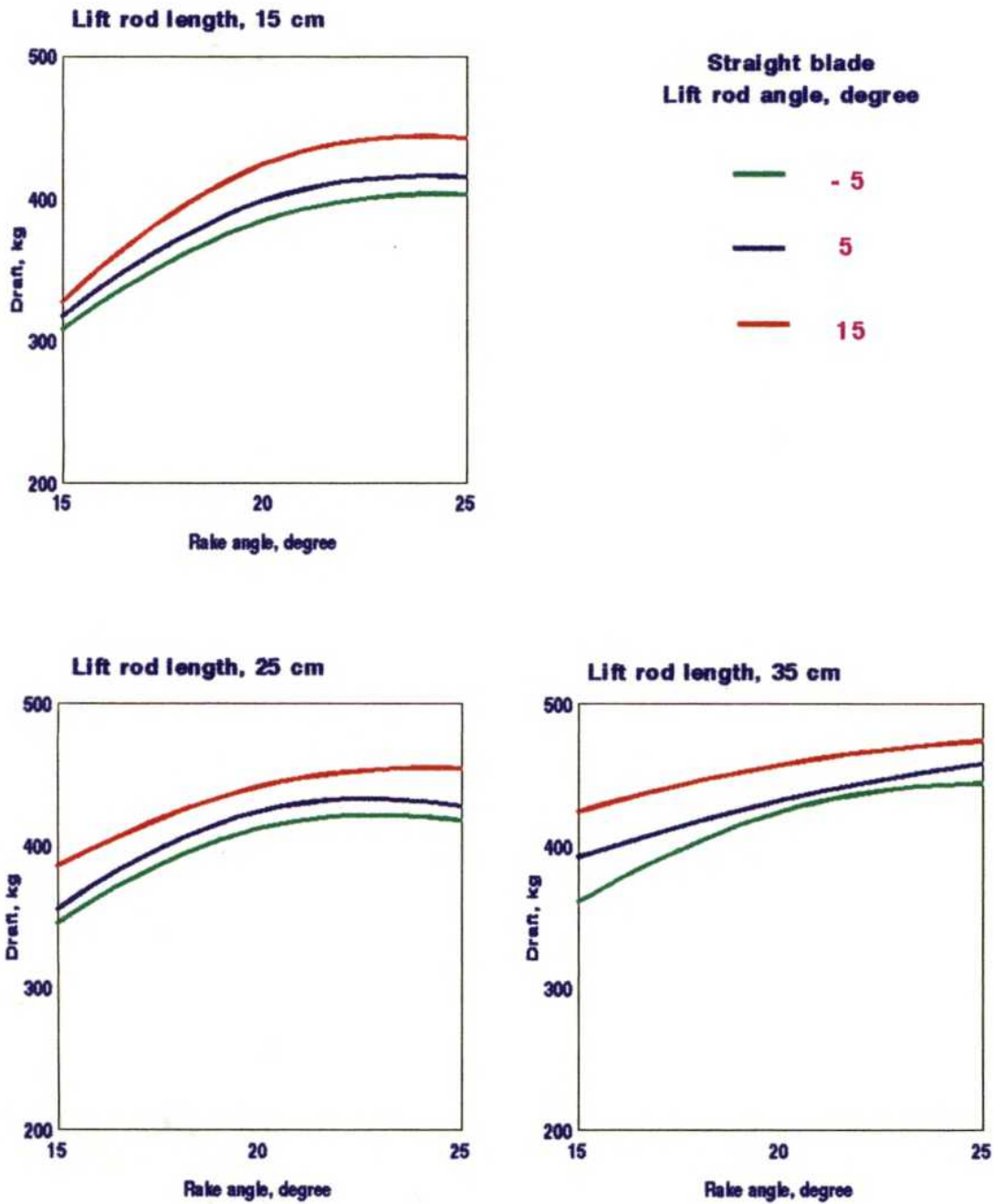


Fig.4.6. Effect of rake angle on draft at different lift rod angles

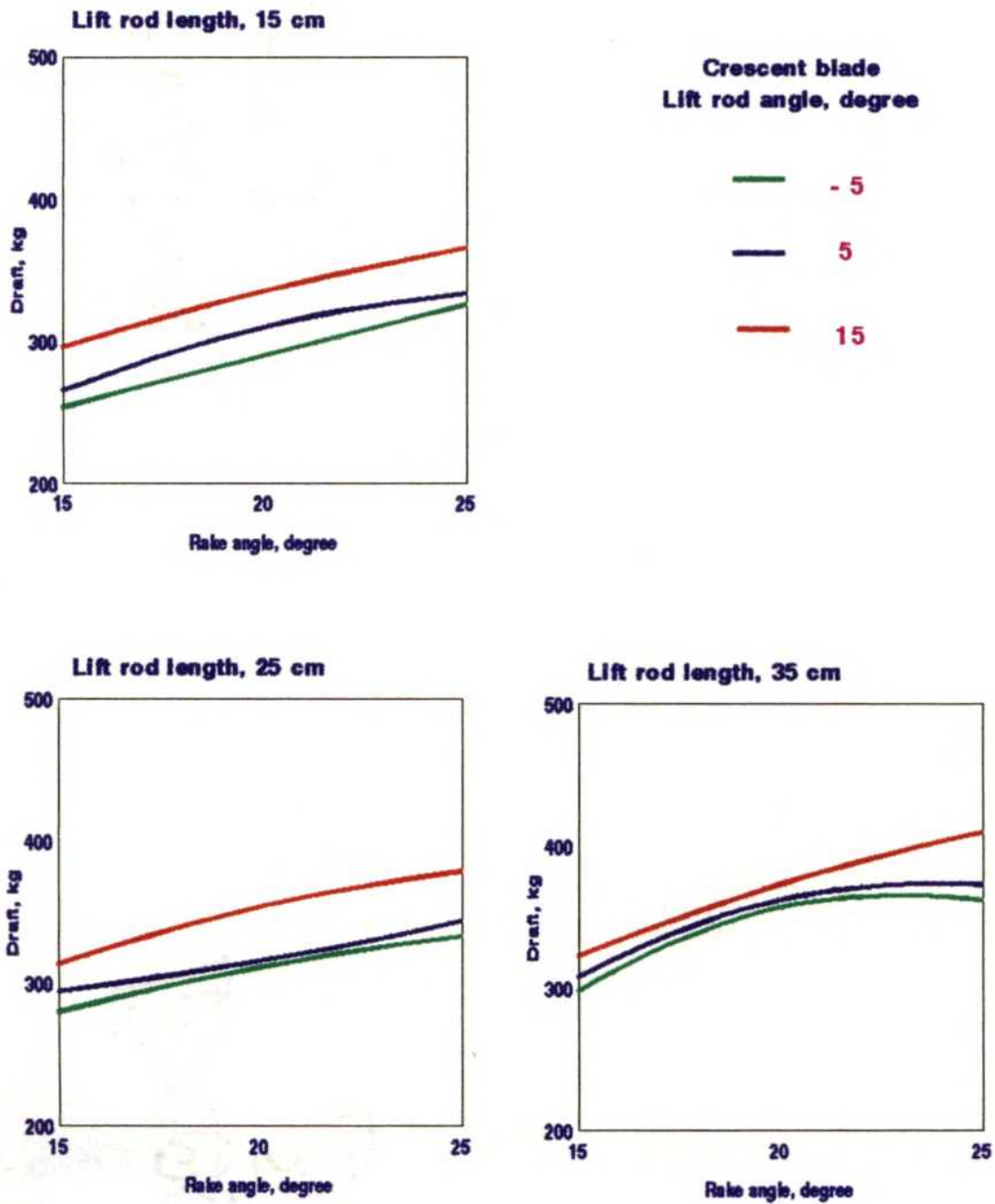


Fig.4.7. Effect of rake angle on draft at different lift rod angles

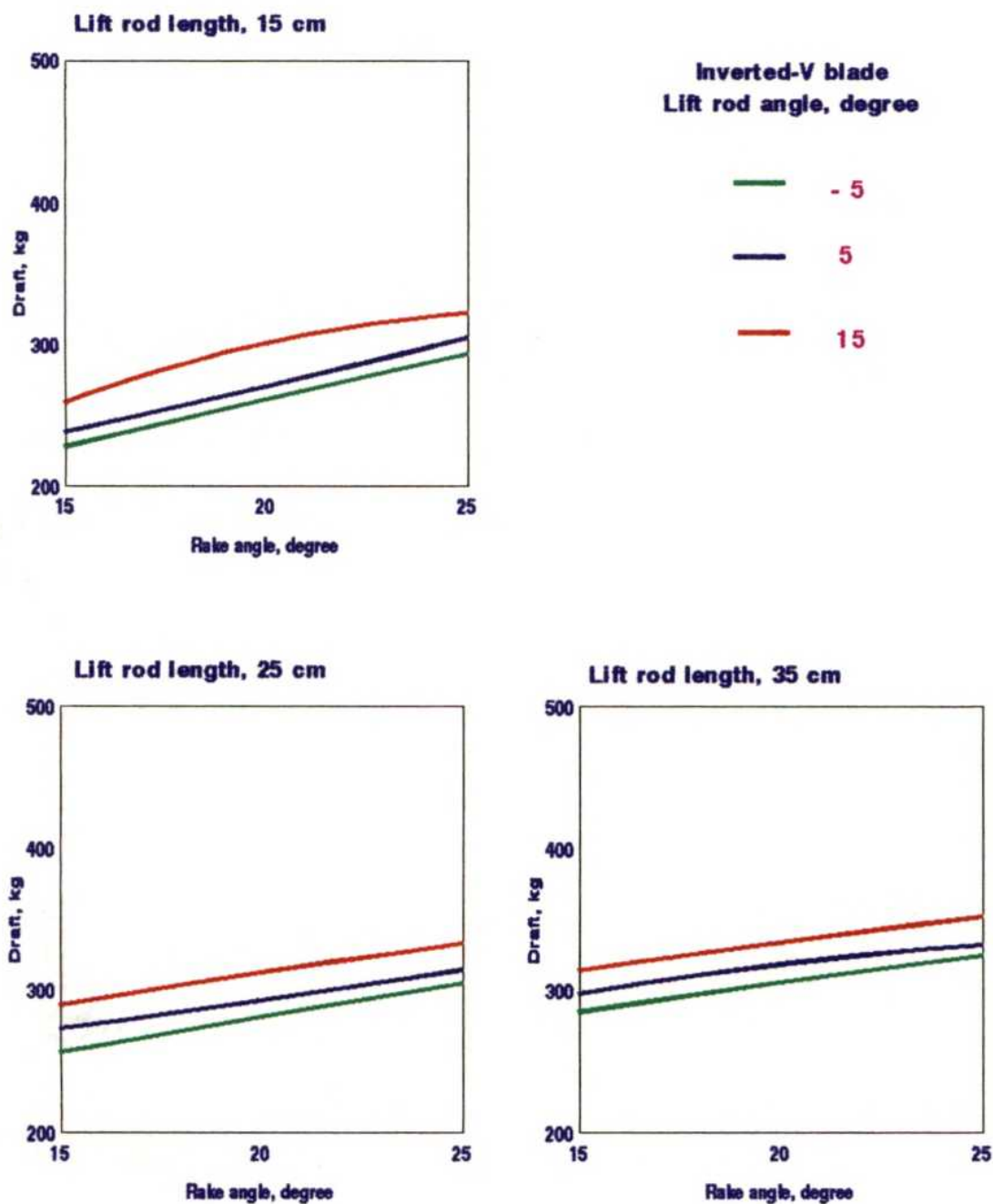


Fig.4.8. Effect of rake angle on draft at different lift rod angles

The M x A means table also indicates the increasing trend in draft at increasing rake angle at all levels of lift rod angle and at increasing lift rod angle at every level of rake angle which is also demonstrated in Figs. 4.6 to 4.8.

b) Effect of tool geometry on draft

The main effect of tool geometry shape on draft had significant influence with the straight blade experiencing maximum draft and the inverted-V shaped blade showing minimum draft.

The interaction effect of tool geometry shape with different lift rod lengths and lift rod angles on draft is presented in Table 4.16. The interaction effects of A x T, L x T and M x T were significant implying that the draft at different tool geometry shapes was influenced by the rake angle, lift rod length and lift rod angle.

Table 4.16. Interaction effects of LxT and MxT factors means on draft

LxT table of means for draft (kg)

Tool shape (T)	Lift rod length (L)			T - mean
	15 cm	25 cm	35 cm	
Straight	380.0	407.1	429.7	405.6
Crescent	308.4	325.0	351.8	328.4
Inverted-V	275.2	295.4	318.4	296.3
L- mean	321.2	342.5	366.6	343.4

MxT table of means for draft (kg)

Tool shape (T)	Lift rod angle (M)			T - mean
	-5 Deg	5 Deg	15 Deg	
Straight	388.9	402.3	425.7	405.6
Crescent	312.4	322.9	349.9	328.4
Inverted-V	282.3	293.6	313.2	296.3
M - mean	327.8	339.6	362.9	343.4

As discussed under sec. 4.4.1.2.a, the interaction of tool shapes with rake angles had significant effect on draft. 15 deg rake angle had minimum draft of 271.1, 292.3 and 357 kg for inverted-V, crescent and straight shaped tool respectively. The draft for other rake angles, viz., 20 and 25 deg also had increased in the same order for all the shapes. Among the 20 and 25 deg rake angles, 20 deg experienced lesser draft.

The tool shape had direct impact on draft at every tool length with the straight blade recording the maximum draft of 380 to 429.7 kg and the inverted V shaped tool showing minimum draft of 275.2 to 388.4 kg for the lift rod lengths. The crescent shaped tool worked at a draft of 330.7 to 373.9 kg for different lift rod lengths. The increasing draft requirement for increasing lift rod length for the different tools is also illustrated in Figs. 4.6 to 4.8.

The M x T table of means shows that there was significant increase in the draft when the lift rod angle was increased in all the three tool shapes. At each lift rod angle, the draft requirement for the three tool shapes showed significant variation, with the straight blade tool requiring maximum draft of 388.9 to 425.7 kg and the inverted V shaped tool requiring minimum draft of 282.3 to 313.2 kg. The crescent shaped tool recorded the draft of 312.4 to 349.9 kg. The increasing effect on draft on account of increase in lift rod angle for different tool geometry shapes is illustrated in Figs. 4.6 to 4.8.

c) Effect of lift rod length on draft

The main effect of lift rod length had significant influence on draft with the draft increasing with lift rod length.

The interaction effects of lift rod length with different lift rod angle on draft is given in Table 4.17.

Table 4.17. MxL table of means for draft (kg)

Lift rod length (L)	Lift rod angle (M)			L - mean
	-5 deg	5 deg	15 deg	
15 cm	305.3	316.9	341.4	321.2
25 cm	327.0	337.9	362.6	342.5
35 cm	351.3	363.9	384.7	366.6
M - mean	327.8	339.6	362.9	343.4

Table 4.17 also shows the increasing trend of draft at increasing lift rod length in all the three lift rod angles and vice-versa which is also illustrated in Figs. 4.6 to 4.8. The interaction effects of L x T and L x A have already been discussed in sec. 4.4.1.2.a and 4.4.1.2.b.

d) Effect of lift rod angle on draft

The main effect of lift rod angle had significant impact on draft with increasing trend with the increasing lift rod angle.

From the M x T, M x A and M x L tables of means for draft, it can be understood that the increase in lift rod angle significantly increased the draft at all levels of rake angle, lift rod length and tool geometry shapes.

The interaction effects of lift rod angle with rake angle, tool geometry shape and lift rod length on draft are discussed in sec. 4.4.1.2.a, b and c respectively.

e) Multiple linear regression analysis for draft

The multiple linear regression analysis was carried out separately for each tool shape with draft required as dependent variable and rake angle, lift rod angle and lift

rod length as independent variables. The results obtained are given in Annexure-XIII to XV.

The regression equations obtained for draft requirement for mechanical harvesting of turmeric are,

For straight blade,

$Y = 173.0 + 2(X_1) + 2(X_2) + 8(X_3)$ with R^2 value of 0.86 significant at 1 per cent level.

For crescent shaped blade,

$Y = 132.2 + 2(X_1) + 2(X_2) + 7(X_3)$ with R^2 value of 0.93 significant at 1 per cent level.

For inverted V shaped blade

$Y = 136.3 + 2(X_1) + 2(X_2) + 5(X_3)$ with R^2 value of 0.86 significant at 1 per cent level.

where,

Y	=	Draft, kg
X ₁	=	Lift rod angle, deg
X ₂	=	Lift rod length, mm
X ₃	=	Rake angle, deg

The values of regression coefficient R^2 namely, 0.86, 0.93 and 0.86 for straight, crescent and inverted-V shaped tools respectively indicated that 86, 93 and 86 per cent of the variations in draft required in respective tool shapes for mechanical harvesting of turmeric was influenced by all the parameters considered. The R^2 values were significant at 1 per cent level confirming the significance of the selected variables in prediction of draft. The regression equations showed significant positive correlation with lift rod angle, lift rod length and rake angle with the rake angle having higher

contribution in all the three shapes. It implies that draft increased significantly with increase in lift rod angle, lift rod length and rake angle.

4.4.1.3. Analysis of variance for damage to rhizome

The third performance parameter namely, percentage damage to the harvested crop, was assessed by varying the tool factors at different levels as given in Table 3.2, and the results obtained for analysis of variances are given in Table 4.18.

4.18. Analysis of variance for percentage damage to rhizome

SV	DF	SS	MS	F
Treatment	80	2104.417	26.305	430.44 **
Lift rod angle (M)	2	0.652	0.326	5.33 **
Lift rod length (L)	2	1.484	0.742	12.14 **
Rake angle (A)	2	521.830	260.915	4265.47 **
Tool shape (T)	2	1511.632	755.816	12356.17 **
M x L	4	1.825	0.456	7.46 **
M x A	4	1.681	0.420	6.87 **
M x T	4	0.337	0.084	1.38 ns
L x A	4	2.372	0.593	9.70 **
L x T	4	5.036	1.259	20.58 **
A x T	4	48.534	12.133	198.36 **
M x L x A	8	0.903	0.112	1.85 ns
M x L x T	8	1.452	0.181	2.97 **
M x A x T	8	2.766	0.345	5.65 **
L x A x T	8	2.487	0.310	5.08 **
M x L x A x T	16	1.417	0.088	1.45 ns
Error	162	9.909	0.061	
Total	242	2114.327		

cv - 3.9 %

** - significant at 1% level; ns - not significant

From the above table, it is found that main effect of each factor namely tool shape (T), rake angle (A), lift rod length (L) and lift rod angle (M) were significant at 1 per cent level indicating that each factor was individually influencing the damage caused to the rhizome at the time of harvest. The interaction effects A x T, L x T,

L x A, M x L, M x A, M x L x T, M x A x T and L x A x T were significant at 1 per cent level.

a) Effect of rake angle on damage

The main effect of rake angle significantly influenced the damage caused to the rhizome with the percentage of damage reducing with increase in rake angle.

The interaction effect of rake angle with different tool geometry shapes, lift rod lengths and lift rod angles on damages caused to rhizome are stated in Table 4.19. The interaction effects of A x T, L x A and M x A showed highly significant influence on damage implying that the damage decreased with increase in rake angle and lift rod length, but decreased upto 5 deg and increased further with further increase in lift rod angle.

Table 4.19. Interaction effects of AxT, LxA and Mx A factors means on damage

AxT table of means for damage (per cent)

Tool shape (T)	Rake Angle (A)			T - mean
	15 deg	20 deg	25 deg	
Straight	7.56	5.73	4.39	5.89
Crescent	5.19	2.71	2.64	3.51
Inverted-V	12.10	9.37	7.25	9.58
A- mean	8.28	5.94	4.76	6.33

LxA table of means for damage (per cent)

Rake angle (A)	Lift rod length (L)			A - mean
	15 cm	25 cm	35 cm	
15 Deg	8.51	8.34	8.00	8.28
20 Deg	5.97	5.90	5.95	5.94
25 Deg	4.76	4.80	4.72	4.76
L - mean	6.41	6.35	6.22	6.33

MxA table of means for damage (per cent)

(Table 4.19 contd...)

Rake angle (A)	Lift rod angle (M)			A - mean
	-5 deg	5 deg	15 deg	
15 Deg	8.24	8.23	8.39	8.28
20 Deg	5.84	5.84	6.13	5.94
25 Deg	4.84	4.76	4.67	4.76
M - mean	6.30	6.28	6.40	6.33

From the A x T table, it is seen that as the rake angle increased, the percentage damage to harvested rhizome decreased in all three types of tools which is illustrated in Figs. 4.9 to 4.11. However, the reduction in damage for crescent shaped blade was marginal when the rake angle was increased from 20 deg to 25 deg level. The treatment combination of T₂A₂L₂M₂ showed the minimum damage of 2.42 per cent.

The damage to rhizome was maximum at 7.25 to 12.10 per cent with inverted-V shaped tool at all rake angle levels and minimum at 2.64 to 5.19 per cent with crescent blade at all rake angle levels.

L x A table shows that the increase of rake angle at every lift rod length reduced the damage but increase of lift rod length at every level of rake angle, did not show any significant change in damage. Figures 4.9 to 4.11 indicate the effect of rake angle on lift rod length as almost negligible in crescent shaped tool.

M x A table also shows that the interaction between rake angle and lift rod angle is more pronounced at different rake angle levels with the percentage damage reduced at increased rake angle in all lift rod angles.

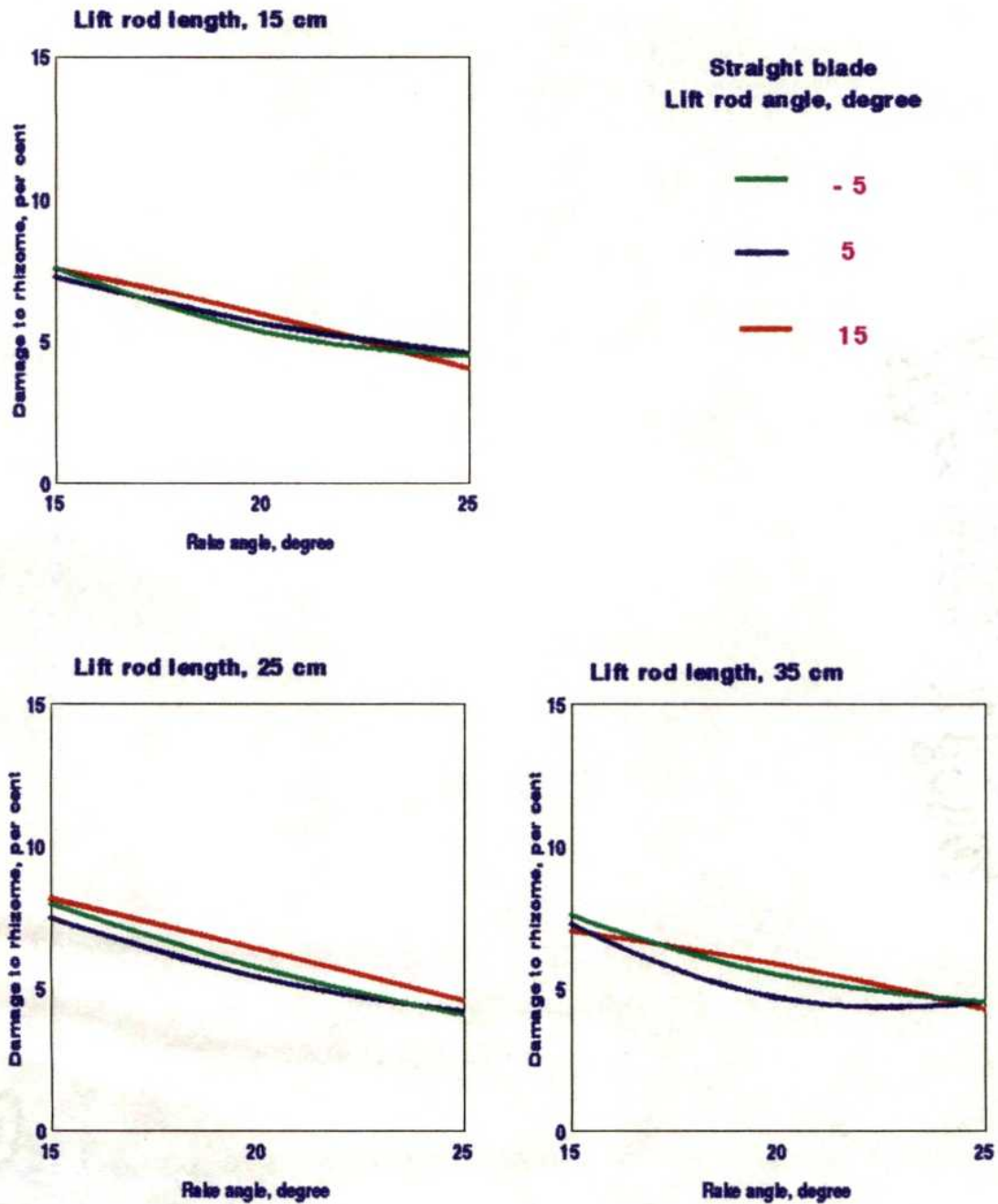


Fig.4.9. Effect of rake angle on damage to rhizome at different lift rod angles

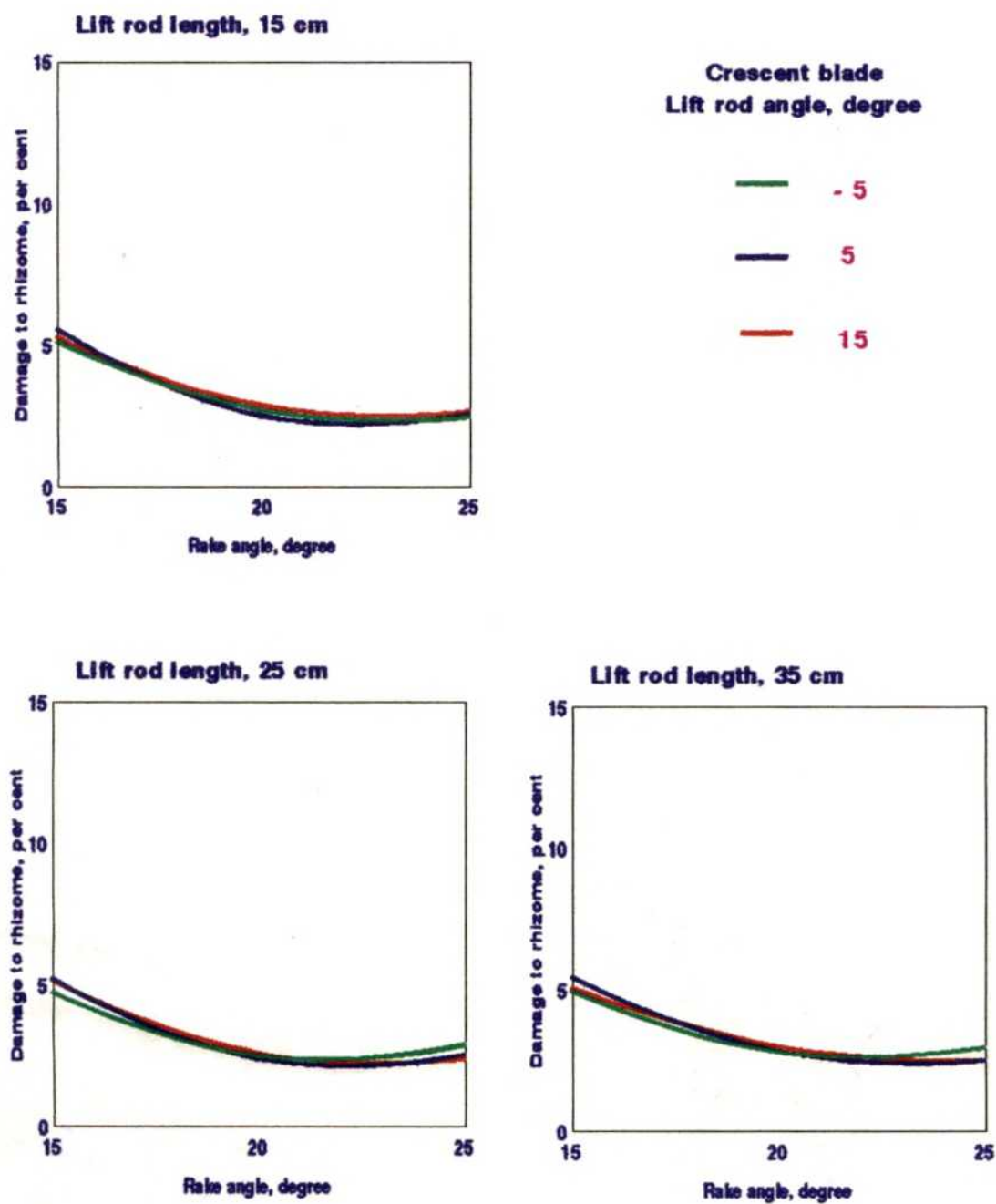


Fig.4.10. Effect of rake angle on damage to rhizome at different lift rod angles



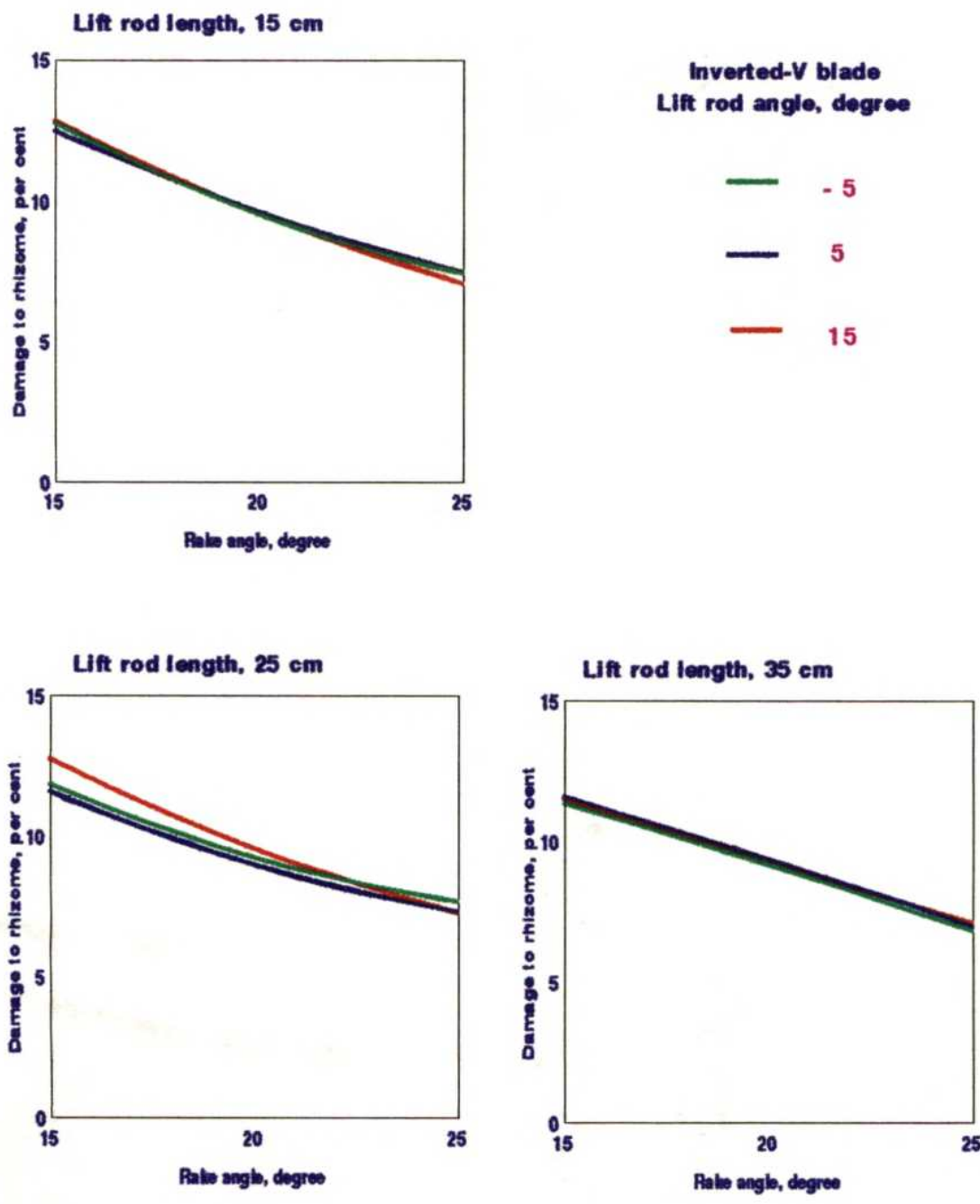


Fig.4.11. Effect of rake angle on damage to rhizome at different lift rod angles

b) Effect of tool geometry on damage

The main effect of tool geometry shapes on damage to rhizome is significant revealing that the crescent shaped tool caused least damage to rhizome compared to other two tools.

The interaction effects of tool geometry shapes on percentage damage to rhizomes with varying lift rod lengths and lift rod angles are recorded in Table 4.20. The interaction effects of A x T and L X T showed high significance on damage to rhizome which indicate that the damage caused to rhizome for different tool shapes was influenced by the rake angle and lift rod length, while the lift rod angle did not exert significant influence.

Table 4.20. Interaction effects of LxT and MxT factors means on damage

LxT table of means for damage (per cent)

Tool shape (T)	Lift rod length (L)			T - mean
	15 cm	25 cm	35 cm	
Straight	5.83	6.03	5.83	5.89
Crescent	3.53	3.41	3.59	3.51
Inverted-V	9.87	9.60	9.25	9.58
L- mean	6.41	6.35	6.22	9.58

MxT table of means for damage (per cent)

Tool shape (T)	Lift rod angle (M)			T - mean
	-5 Deg	5 Deg	15 Deg	
Straight	5.88	5.80	5.99	5.89
Crescent	3.48	3.53	3.52	3.51
Inverted-V	9.54	9.50	9.68	9.58
M - mean	6.30	6.28	6.40	6.33

As the tool geometry shape was varied, the percentage damage to the harvested crop was reduced to a minimum at 3.41 to 3.59 per cent for crescent shaped tool from

that straight blade but increased further for inverted V shaped blade in all levels of lift rod length. This trend is illustrated in Figs. 4.9 to 4.11. From Table 4.19 it is seen that the damage was reduced when the tool shape was changed from straight to crescent and the damage increased when the tool shape was changed from crescent to inverted-V tool indicating that the crescent shaped tool caused minimum damage to the tools. Figs. 4.9 to 4.11 demonstrate the behaviour of tool geometry shapes in interaction with other variables on damage caused to rhizome.

c) Effect of lift rod length on damage

The main effect of lift rod length had influential impact on damage caused to rhizome which meant that the 350 mm lift rod caused minimum damage.

The interaction effect of lift rod lengths on damage caused to rhizomes with different lift rod angles is revealed in Table 4.21.

Table 4.21. MxL table of means for damage (per cent)

Lift rod length (L)	Lift rod angle (M)			L - mean
	-5 deg	5 deg	15 deg	
15 cm	6.39	6.41	6.43	6.41
25 cm	6.32	6.15	6.57	6.35
35 cm	6.20	6.27	6.20	6.22
M - mean	6.30	6.28	6.40	6.33

It can be seen from M x L table that increase in lift rod length reduced the damages significantly at all lift rod angle positions but increase in lift rod angle had only marginal effect on damages. The lift rod length of 250 mm caused minimum damage at lift rod angle of 5 deg.

d) Effect of lift rod angle on damage

The main effect of lift rod angle on damage was significant and indicated that the 5 deg lift rod angle caused minimum damage when compared with other two angle positions.

The interaction effect of M x T, M x A and M x L means tables state that increase in lift rod angle showed insignificant effect on damage with tool geometry shapes, but significant effect with all rake angle levels and marginal effect with all lift rod lengths. The 15 deg lift rod angle showed minimum damage at 25 deg rake angle.

e) Multiple linear regression analysis for damage to rhizome

The multiple linear regression analysis was carried out with damages caused to rhizomes at the time of harvest as dependent variable, and rake angle, lift rod angle and lift rod length as independent variables for the three shapes tools separately.

The results are given in Annexure - XVI to XVIII. The regression equations obtained for damage to rhizomes were,

$Y = 12.213 + 0.01 (X_1) + 0.00001 (X_2) - 0.3 (X_3)$ at R^2 value of 0.94
for straight blade,

$Y = 8.538 + 0.002 (X_1) + 0.003 (X_2) - 0.3 (X_3)$ at R^2 value of 0.72
for crescent shaped blade,

$Y = 20.002 + 0.01 (X_1) - 0.03 (X_2) - 0.5 (X_3)$ at R^2 value of 0.87 for
inverted V shaped blade

where,

Y = Damages caused to rhizomes, per cent

X₁ = Lift rod angle, deg

X₂ = Lift rod length, mm

X₃ = Rake angle, deg

The R^2 values revealed that 94, 72 and 87 per cent of the variation in damage to rhizomes by mechanical harvesting in straight, crescent and inverted V shaped tools respectively were influenced by all the parameters considered. The regression coefficient values were significant at 1 per cent level confirming the significance of the selected variables for prediction of extent of damage caused to rhizomes.

The regression equations showed positive correlation with lift rod angle in all tool shapes, positive correlation with lift rod length in straight and crescent shaped blades and negative correlation with lift rod length in inverted V shaped blade. The rake angle had negative correlation in all tool shapes. As the lift rod angle increased, the damage also increased marginally. As the lift rod length increased, the damage also increased marginally for straight and crescent shape blade but reduced for inverted V shape blade. The increase in rake angle reduced the damage to rhizomes in all the three shapes of tools. This shows that the crescent shaped blade is preferable to other two blades in terms of lesser damage to the rhizome.

4.4.2. Selection of best combination of factors

The test results conducted with three shapes of tools, namely, straight, crescent and inverted V, for harvesting turmeric, were statistically analysed in terms of harvesting efficiency, draft and damage to rhizomes. The foregoing discussions in sec. 4.4.1, 4.4.2 and 4.4.3 indicate that the crescent shaped blade, rake angle of 20 deg, lift rod angle of 5 deg and 250 mm lift rod length as the best variable levels for maximum harvesting efficiency, minimum draft and minimum damage. The analysis of variance and factor means revealed that maximum harvesting efficiency occurred in the

combination $T_2A_2L_2M_2$ comparing all possible combination of interactions. However in the process of selection, minimum draft and minimum damage to rhizomes also has to be considered along with maximum harvesting efficiency. The statistical analysis of data indicated that the combination of $T_3A_1L_1M_1$ and $T_2A_2L_2M_2$ could result in a minimum draft and damage to rhizomes respectively. The following table shows the best combination for the three dependent variables of harvesting efficiency, draft and damage to rhizome.

Sl. No.	Factor combination	Harvesting efficiency (%)	Draft (kg)	Damage (%)	Remarks
1.	$T_2A_2L_2M_2$	97.60	315.70	2.42	Maximum harvesting efficiency & minimum damage
2.	$T_2A_1L_1M_1$	88.03	227.70	12.80	Minimum draft

Other possible combinations showing less draft are also taken into consideration as given below:

$T_2A_2L_1M_2$ with 2.5 per cent damage, 96.5 per cent harvesting efficiency and 310 kg draft and $T_2A_3L_3M_3$ with 2.53 per cent damaged, 93.23 per cent harvesting efficiency and 410 kg draft.

But the harvesting efficiency of the above mentioned combinations are lower than the combination $T_2A_2L_2M_2$. In the present case, the maximum harvesting efficiency combined with minimum damage to the rhizome has to be preferred over the minimum draft, to maximise the yield realisation in turmeric which is the major objective of this study. In this way, the combination namely $T_2A_2L_2M_2$ (crescent shaped tool, 20 deg rake angle, 250 mm lift rod length and 5 deg lift rod angle) has

been selected as the best combination due to its maximum harvesting efficiency of 97.6 per cent and minimum damage of 2.42 per cent caused to rhizome even though the draft of 315.7 kg recorded for this combination was higher than the minimum draft of 227.7 kg for T₃A₁L₁M₁ combination. The higher draft of 315.7 kg was however within the pulling power of the tractor and hence the combination of T₂A₂L₂M₂ is found to be the best combination in all respects.

The optimised rake angle of 20 deg in this study is also in agreement with the findings of Osman (1964) for wider cutting tools and of Hettiaratchi and Reece (1967), Godwin and Spoor (1977), Mckyes and Ali (1977) and Perumpral *et al* (1983) for narrow tillage tools and Gill and Vandenberg (1967) for shallow depths of ploughing.

Therefore the optimised levels of parameters considered for the prototype harvester (Plates 4.1, 4.2, 4.3) are as follows :

Tool length	-	450 mm
Tool width	-	250 mm at centre
Tool thickness	-	10 mm
No. of tools	-	Two
Speed of operation	-	2.5 kph
Depth of operation	-	200 mm
Tool shape	-	Crescent
Rake angle	-	20 deg to horizontal
Lift rod length	-	250 mm
Lift rod angle	-	5 deg to horizontal
Optimum soil moisture for harvest	-	9.2 - 10.05 per cent (db) in sandy loam soil 15.01 - 16.70 per cent (db) in clay loam soil



Plate 4.1. Prototype tractor drawn turmeric harvester- front view



Plate 4.2. Prototype tractor drawn turmeric harvester-side view



Plate 4.3. Prototype turmeric harvester mounted on the tractor

4.5. Field performance evaluation of the prototype harvester

Field performance evaluation tests of the prototype harvester with various tool parameters set at the optimised levels were carried out in terms of harvesting efficiency, effective field capacity, field efficiency, draft, extent of damage to harvested crop, cost of operation etc., for 3 varieties of turmeric, namely Erode, Salem and BSR-1 in clay loam and sandy loam soils, in which turmeric is predominantly grown. The evaluation was carried out as per procedure laid out by RNAM (Anon., 1983). The observations were recorded for three replications. The evaluation data in comparison with manual method is presented in Table 4.22a and 4.22b. The field evaluation of the prototype harvester is illustrated in Plates 4.4, 4.5 and 4.6.

Table 4.22a Performance tests - Manual harvesting

Particulars	Manual harvesting Erode variety					
	1	2	3	4	5	6
A. Test conditions						
1. Crop and variety-turmeric	Erode					
2. Date of planting	1.6.98	1.6.98	1.6.98	1.6.98	1.6.98	1.6.98
3. Row spacing - cm	45	45	45	45	45	45
4. Hill distance - cm	20	20	20	20	20	20
5. Plant population per sq.m	13	13	13	13	13	13
6. No. of tillers per plant	7	7	7	7	7	7
7. Av.No. of rhizomes /sq.m	13	13	13	14	13	13
8. Wt.of rhizomes per plant (Av.10 readings) - kg	0.225	0.225	0.225	0.225	0.225	0.225
9. Av.yield / sq.m - kg	2.925	2.925	2.925	3.15	2.925	2.925
10. Av.yield - kg per ha	29250	29250	29250	31500	29250	29250
B. Field Conditions						
1. Location	Irutu Pallam					
2. Soil type	Clay loam					
3. Length - m	40	40	40	40	40	40
4. Width - m	25	25	25	25	25	25
5. Area - m ²	1000	1000	1000	1000	1000	1000
6. Soil moisture - %	18.10	18.2	18.2	17.5	18.1	17.6

(Table 4.22a Contd...)

C. Operator conditions						
1. Wage of tractor operator per day - Rs.	--	--	--	--	--	--
2. Wage for manual digging per day - Rs.	80	80	80	80	80	80
3. Wage for picking per day - Rs.	40	40	40	40	40	40
D. Field performance						
1. Actual operation time	2h 10 min	2 h 15 min	2 h 20 min	2h 35 min	2 h 10 min	2h
2. Time lost in turns	--	--	--	--	--	--
3. Time lost in adjustment	--	--	--	--	--	--
4. Effective working width - m	--	--	--	--	--	--
5. Effective field capacity - hah ⁻¹	0.0462	0.0444	0.0429	0.0387	0.0462	0.0500
6. Field efficiency - %	--	--	--	--	--	--
7. Speed of machine - kph	--	--	--	--	--	--
8. Fuel consumption - l per h l per ha	--	--	--	--	--	--
9. Rhizomes left undug - %	10.60	11.71	10.70	13.30	12.5	13.6
10. Harvesting efficiency - %	89.40	88.29	89.3	86.7	87.5	86.4
11. Damages - %	8.1	8.6	8.0	7.9	7.3	9.4
12. Draft - kg	--	--	--	--	--	--
13. Labour used	--	--	--	--	--	--
a. Tractor operator - No. Man hours - h	--	--	--	--	--	--
b. Skilled labour for digging - No. Skilled labour Man hours	10 21.6	10 22.5	10 23.3	10 25.8	10 21.6	10 20
c. Women labour for picking - No	13	13	13	14	13	13
14. Total labour requirement / ha	--	--	--	--	--	--
a. Tractor operator - Man days	--	--	--	--	--	--
b. Skilled labour - Man days	27.0	28.13	29.13	32.25	27.0	25.00
c. Women labour - woman days	130	130	130	140	130	130
d. Total cost of labour / ha - Rs.	7360	7450	7530	7760	7360	7200
e. Cost of labour / tonne - Rs.	251.60	254.70	257.45	246.35	251.60	246.15
f. Total cost of operation / ha	7360	7450	7530	7760	7360	7200

Table. 4.22b Performance tests - Mechanical harvester

Particulars	Mechanical harvester								
	Erode			Salem			BSR-I		
	1	2	3	1	2	3	1	2	3
A. Test conditions									
1. Crop and variety-turmeric	Erode	Erode	Erode	Salem	Salem	Salem	BSR-I	BSR-I	BSR-I
2. Date of planting	1.6.98	1.6.98	1.6.98	17.6.98	17.6.98	17.6.98	21.6.98	21.6.98	21.6.98
3. Row spacing - cm	45	45	45	45	45	45	60	60	60
4. Hill distance - cm	18	18	18	20	20	20	20	20	20
5. Plant population per sq.m	13	13	14	11.5	11.5	11.8	8.3	8.4	8.6
6. No. of tillers per plant	7	7	7	6	6	6	7	7	6
7. Av.No. of rhizomes /sq.m	13	13	14	11.5	11.5	11.8	8.3	8.4	8.6
8. Wt.of rhizomes per plant (Av.10 seedings) - kg	0.225	0.225	0.225	0.261	0.261	0.261	0.3	0.3	0.295
9. Av.yield / sq.m - kg	2.925	2.925	3.15	3.001	3.001	3.080	2.49	2.52	2.537
10. Av.yield - kg per ha - kg	29250	29250	31500	30010	30001	30800	24900	25200	25390
B. Field Conditions									
1. Location	Irutu pallam			Thondamuthur			Bhavanisagar		
2. Soil type	Clay loam			Clay loam			Red sandy loam		
3. Length - m	120	118	155	100	95	100	100	85	90
4. Width - m	45	42	34	51	55	47	50	60	50
5. Area - m ²	5400	4956	5270	5100	5225	5170	5000	5100	4500
6. Soil moisture - %	15.79	15.80	16.30	15.01	15.69	15.92	10.02	10.05	9.90
C. Operator conditions									
1. Wage of tractor operator per day - Rs.	100	100	100	100	100	100	100	100	100
2. Wage for manual digging per day - Rs.	--	--	--	--	--	--	--	--	--
3. Wage for picking per day - Rs.	40	40	40	40	40	40	40	40	40
D. Field performance									
1. Actual operation time	2h 45 min	2 h 25 min	2 h 40 min	2h 40 min	2 h 45 min	2h 42 min	1 h 45 min	1 h 50 min	1 h 35 min
2. Time lost in turns	15 min	8 min	15 min	15 min	15 min	15 min	15 min	15 min	15 min
3. Time lost in adjustment	10 min	5 min	10 min	10 min	10 min	10 min	10 min	10 min	10 min
4. Effective working width - m	0.90	0.90	0.90	0.90	0.90	0.90	1.2	1.2	1.2
5. Effective field capacity - kph	0.192	0.205	0.195	0.190	0.193	0.190	0.286	0.278	0.284
6. Field efficiency - %	85.3	88.0	86.7	84.4	84.7	84.5	95.3	92.6	94.6
7. Speed of machine - kph	2.5	2.58	2.5	2.5	2.5	2.52	2.5	2.5	2.5
8. Fuel consumption - l per h	3.1	3.2	3.1	3.15	3.2	3.16	3.1	3.2	3.1
9. Rhizomes left undug - %	16.15	15.70	15.9	16.3	16.5	16.6	10.8	11.5	10.9
10. Rhizomes left undug - %	2.45	2.55	2.47	2.80	2.69	2.71	2.2	2.41	2.39
11. Harvesting efficiency - %	97.55	97.45	97.43	97.20	97.31	97.29	97.8	97.59	97.61
12. Damages - %	2.80	2.71	2.69	2.6	3.0	2.7	2.7	3.2	2.8
12. Draft - kg	325	330	340	330	345	328	295	290	320
13. Labour used									
a. Tractor operator - No.	1	1	1	1	1	1	1	1	1
Tractor Man hours	2.8	2.4	2.7	2.7	2.7	2.7	1.75	1.8	1.6
b. Skilled labour digging - No.	--	--	--	--	--	--	--	--	--
Skilled labour Man hours	--	--	--	--	--	--	--	--	--
c. Total labour for picking- No	64	60	66	64	66	65	63	64	56
14. Total labour requirement/ha									
a. Tractor operator - Man days	0.65	0.60	0.64	0.66	0.65	0.65	0.44	0.44	0.44
b. Skilled labour - Man days	--	--	--	--	--	--	--	--	--
c. Women labour- women days	118	121	125	123	126	126	126	125	124
d. Total cost of labour/ha - Rs.	4785	4900	5064	5066	5105	5705	5084	5044	5004
e. Cost of labour / tonne - Rs.	163.60	167.50	160.75	168.80	170.10	165.75	202.40	200.15	197.25
f. Total cost of operation / ha	5253.3	5351.6	5531.5	5157.80	5197.35	5196.90	5175.15	5136.35	5094.15



Plate 4.4. Prototype turmeric harvester working in the field



Plate 4.5. Closer view of turmeric harvester working in the field

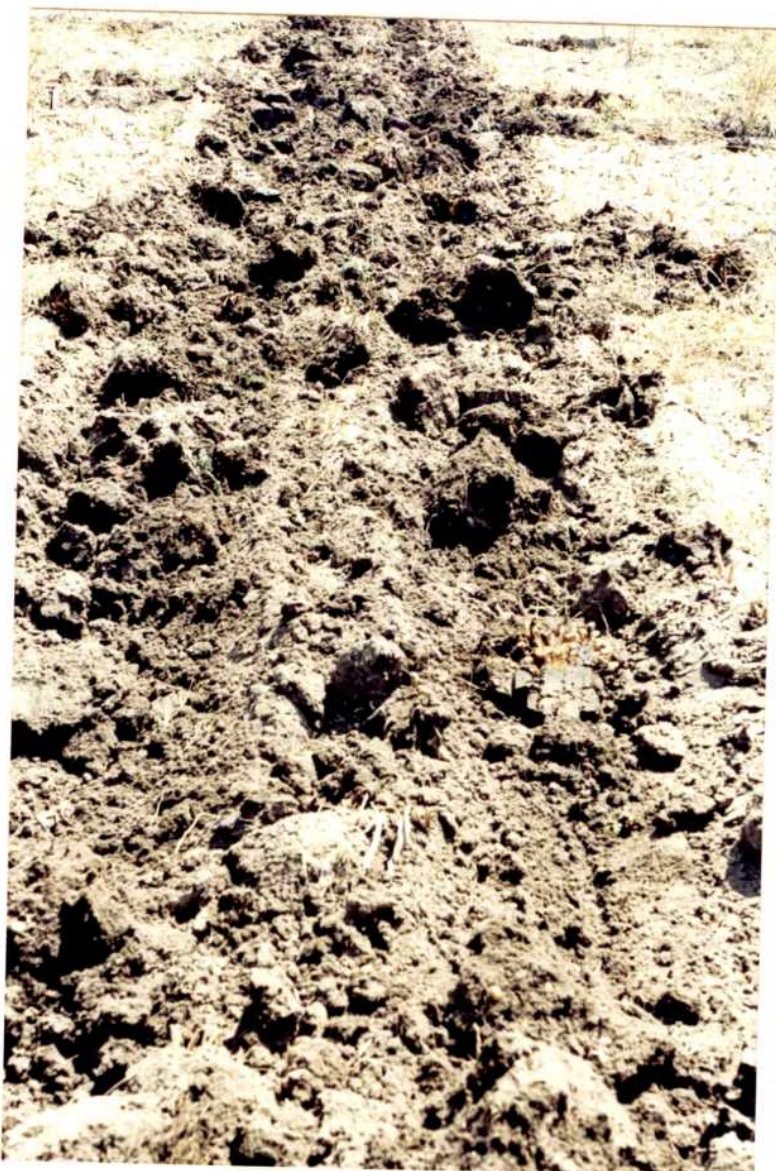


Plate 4.6. Turmeric field harvested with prototype harvester

The mean values of the test results in terms of harvesting efficiency, draft, effective field capacity and damage to the harvested crop for the prototype harvester are given in Table 4.23.

Table 4.23. Field performance of prototype tractor drawn turmeric harvester (mean values of three replications)

Variety	Soil type	Soil moisture per cent	Spacing cm	Harvest. efficiency per cent	Draft kg	Effective field capacity ha h ⁻¹	Damage per cent	Field efficiency per cent	Cost of operation Rs ha ⁻¹
Erode	Clay loam	15.96	45 x 20	97.48	331.6	0.197	2.73	86.66	5379.50
Salem	Clay loam	15.54	45 x 20	97.26	333.3	0.191	2.80	84.53	5184.00
BSR-1	Sandy loam	9.99	60 x 20	97.66	290.0	0.282	2.90	94.16	5135.55

The effective field capacity was about 0.191 to 0.197 ha per h but it was higher in the trails conducted with BSR-1 variety due to adoption of wider spacing of 60 x 20 cm. The harvesting efficiency was 97.26 to 97.66 per cent, with damage caused to the harvested crop being 2.33 to 2.90 per cent. The performance by manual harvesting as discussed in Sec.4.1. has shown a harvesting efficiency of 87.93 per cent with damage caused to rhizome being 8.21 per cent. Therefore, it can be seen that the mechanical harvesting with a tractor drawn harvester was superior to manual harvesting in terms of higher harvesting efficiency and less damage to the crop. This shows that an additional quantity of about 10 per cent of the crop which otherwise would have been left undug from soil could be realised as yield and thus the productivity per ha could be considerably improved by mechanical harvesting of turmeric.

By reducing the damage in manual harvesting from 8.21 per cent to below 3 per cent in mechanical harvesting, the value of the harvested crop is also increased, thus

bringing additional revenue to the farmer. Considering the high price of Rs.700 per quintal for the fresh rhizome, the additional income that may be generated by reducing the field losses will be considerable.

4.6. Cost economics

The cost economics of the developed prototype turmeric harvester was analysed as per the RNAM test code and procedure for harvesters (Anon., 1983). The break even point and the payback period for the harvester was also calculated.

4.6.1. Cost of harvesting with the mechanical turmeric harvester

Assumptions made,

Initial cost of tractor	=	Rs.2,25,000.00
Initial cost of harvester attachment	=	Rs. 10,000.00
Annual usage for tractor	=	1200 h
" for harvester attachment	=	60 days
Actual working hours per day	=	8 h
Annual usage for harvester attachment	=	480 h
Total life of tractor	=	15 yrs
" Harvester attachment	=	7 yrs
Salvage value 10 % of initial cost, Tractor	=	Rs.22,500.00
" " " Harvester attachment	=	Rs.1,000.00

Annual fixed cost and fixed cost per hour

		Tractor		Harvester attachment	
		Annual	Per hour	Annual	Per hour
1.	Depreciation Rs.	$225000 - 22500 / 15 = 13500$	11.25	$10000 - 1000 / 7 = 1285.70$	2.70
2.	Interest Rs.	$[225000 + 22500] / 2 \times 15/100 = 18562.50$	15.45	$[10000 + 1000] / 2 \times 15/100$	1.40
3.	Housing, 1.5% of purchase price - Rs.	3375	2.80	$10000 \times 1.5 / 100 = 150$	0.30
4.	Taxes 1% of purchase price - Rs.	2250	1.90	-	-
5.	Insurance 1% of Average price - Rs.	$[225000 + 22500] / 2 \times 1/100 = 1238$	1.05	$[10000 + 1000] / 2 \times 1/100 = 55.00$	0.15

6.	Repair & maintenance 8 % of purchase price - Rs.	$225000 \times 8 / 100 = 18000$	15.00	$10000 \times 8 / 100 = 800$	1.67
7.	Total fixed cost Rs.	56926.00	47.45	2951	6.20
8.	Fixed cost for 480 hours	$47.45 \times 480 = 22,776$		2951	
B. Operating cost					
	Operator wages Rs. per hour		12.50	-	-
	Fuel @ Rs.11/lit		33.00	-	-
	Lubrication 10% of fuel		3.30	-	-
	Women labour for picking/ha (125 persons @ Rs.40/day)				5000
	Total operating cost		48.80		Nil + 5000

C. Total cost / hour

$$\begin{aligned}
 &= \text{Total fixed cost} + \text{Total operating cost} \\
 &= 47.45 + 6.20 + 48.89 \\
 &= 102.45 \text{ per h}
 \end{aligned}$$

D. Cost per ha

$$\text{Field capacity} = 0.2 \text{ ha/h}$$

$$\text{Cost per ha} = 102.45 / 0.2 + 5000 = 512.25 + 5000 = 5512.25$$

4.6.2. Cost of harvesting by conventional method

$$\text{Area of field harvested by a skilled labour in one day} = 0.04 \text{ ha}$$

$$\text{Total man days per ha} = 28$$

$$\text{Wages per man day} = \text{Rs.}80$$

$$\text{Cost of digging per ha} = \text{Rs.}2240$$

Women days per ha for picking harvested crop	=	131 women days (Plates 4.7, 4.8)
Wages per woman day	=	Rs.40
Cost of picking per ha	=	Rs.5240
Total cost of labour per ha	=	Rs.2240 + 5240
	=	Rs.7480.00

4.6.3. Savings in Cost

Cost of harvesting with machine	=	Rs.5512.45
Cost by manual harvesting	=	Rs.7480.00
Saving in cost per cent	=	26.3

4.6.4. Break even point

$$\text{Break even point (BEP) ha per annum} = \frac{\text{Annual fixed cost}}{\text{Custom fee / h} - \text{operating cost / h}} \times \text{Effective field capacity ha/h}$$

$$\begin{aligned} \text{Annual fixed cost} &= \text{Fixed cost of tractor for 480 h} + \text{Fixed cost of harvester attachment} \\ &= \text{Rs.22776} + \text{Rs.2951} \\ &= \text{Rs.25727/-} \end{aligned}$$

$$\begin{aligned} \text{Custom fee / h} &= (\text{Cost operation per h} + 25 \text{ per cent overhead charges}) \\ &\quad + 25 \text{ per cent profit over new cost} \\ &= (102.45 + 102.45 \times 0.25) \times 1.25 \\ &= \text{Rs.160 per h} \end{aligned}$$

$$\text{Operating cost per h} = \text{Rs.48.80}$$

$$\text{Effective field capacity} = 0.2 \text{ ha per h}$$

$$\begin{aligned} \text{Breakeven point} &= \frac{25727 \times 0.2}{160 - 48.8} \\ &= 46.27 \text{ ha per annum} \\ &\approx 47 \text{ ha per annum} \end{aligned}$$

$$\begin{aligned} \text{Annual utility, ha} &= \text{Effect field capacity} \times \text{Annual utility period ha} \\ &= 0.2 \times 480 \\ &= 96 \text{ ha} \end{aligned}$$

Plate 4.7. Women labour picking harvested rhizomes

Plate 4.8. Women labour separating the rhizomes and fingers

Therefore,

BEP is achieved at about $47 \times 100 / 96 = 49$ per cent of the annual utility rate of 480 hours of the harvester attachment.

4.6.5. Pay back period

$$\begin{aligned} \text{Pay back period, Yrs} &= \frac{\text{Initial cost of equipment}}{\text{Average net annual benefit}} \\ \\ \text{Initial cost of equipment} &= \text{Initial cost of tractor for 480 h out of 1200 h} \\ &\quad \text{annual usage} + \text{Initial cost of harvester} \\ &\quad \text{attachment} \\ &= 2,25,000 \times 480 / 1200 + 10,000 \\ &= 90,000 + 10,000 \\ &= \text{Rs. 1,00,000} \\ \text{Average nett annual benefit} &= (\text{Custom fee / h} - \text{Total cost of operation / h}) \\ &\quad \times \text{Annual utility rate h} \\ &= (160 - 102.45) \times 480 \\ &= \text{Rs. 27,624/-} \\ \\ \text{Therefore, Pay back period} &= 1,00,000 / 27624 \\ &= 3.62 \text{ years.} \end{aligned}$$

SUMMARY AND CONCLUSIONS

CHAPTER V

SUMMARY AND CONCLUSION

Turmeric is one of the important spice crops, which earns sizable foreign exchange for our country through export of its end products. There is an urgent need to increase the productivity of the crop to meet the demand of 8 lakhs tonnes by 2000 AD while the production at present is about 4.87 lakh tonnes only. Mechanisation of cultivation practices is one of the proven methods of improving the productivity.

Harvesting of turmeric rhizome is one important aspect which requires immediate attention for developing appropriate mechanical technology. Conventional method of harvesting turmeric rhizome is labour intensive, requiring skilled men labour to digout the crop. The non-availability of such skilled labour and the high wages demanded by them to harvest the crop, the higher field losses and damage to the crop by manual harvesting, necessitate the need to develop a suitable mechanical harvester for turmeric. With tractors already becoming a common feature in villages, a mechanical harvester attachment to the tractor will be the most appropriate mechanical harvesting technology. The harvester should satisfy the basic requirements of achieving maximum harvesting efficiency with minimum damage to the crop and at lesser cost. Hence a study was undertaken to optimise various design parameters for developing a suitable mechanical harvester for turmeric that would satisfy all the above requirements.

Appropriate materials, methodologies and instrumentation were adopted for the study. The experiment was conducted in the following aspects.

- a. Pertinent physical properties of the soils in which turmeric is predominantly grown, were determined.
- b. Three varieties of turmeric commonly cultivated in Tamil Nadu, namely Erode, Salem and BSR-I were selected for the study.
- c. Relevant physical properties and the yield attributes of the crop for the above three varieties were determined.
- d. The power required for operating the harvester with two digger blades to harvest alternating rows was calculated and was found to be within the available drawbar power of the tractor.
- e. The dimensions and materials of critical components namely blade and shank were designed.
- f. The length of the digger blade was fixed as 450 mm to suit the row spacing mostly adopted in turmeric.
- g. Two digger blades were designed to be mounted on a standard tractor drawn cultivator of the 2120 x 600 mm frame with hitching arrangement to match the standard three point hydraulic linkage of the tractor.
- h. Necessary provisions were made to adjust the different tool variable levels taken up for the study.

- i. To study the effect of tool shapes, three shapes of harvesting blades namely, straight, crescent and inverted V shaped tools were developed for the experiment.
- j. The tool width of 250 mm at the centre and the designed blade thickness of 10 mm were used for the tool geometry of all the three blades.
- k. Alternation field machine pattern was adopted in such a way that the tractor wheels did not run over the harvested rows at any point of time.
- l. The performance of the tools were evaluated in clay loam soil for harvesting turmeric with different tool shapes, rake angles, lift rod lengths and lift rod angles of the digger blade. Three levels of tool rake angles namely 15,20, and 25 deg; three levels of the lift rod length namely, 150, 250 and 350 mm; and three levels of lift rod inclination namely -5, 5 and 15 deg, were selected for the experiment.
- m. The operational parameters were fixed as 2.5 kph for speed of operation and 200 mm for depth of operation for the experiment.
- n. The experiments were formulated with Factorial Completely Randomized Design (FCRD) and three replications for each treatment combination were tested. There were totally 81 treatment combinations for the experiment.
- o. The performance parameters considered were harvesting efficiency, draft required and percentage damage caused to rhizome at the time of harvest.

- p. The tool combination which gave maximum harvesting efficiency and minimum damage to crop was chosen as the best, based on statistical analysis.
- q. A prototype turmeric harvester was developed from the optimised tool parameters and its field performance was evaluated for harvesting turmeric in comparison with conventional method.

The important findings and conclusion of the study are summarised below

1. The mean values of soil moisture at time of harvest in sandy loam soil were 14.69, 9.70 and 8.31 per cent (d.b) after irrigating the field 3,7 and 12 days prior to harvest respectively while the corresponding values in clay loam soil were 23.97, 15.98 and 11.32 per cent (d.b) respectively.
2. The draft of the experimental tool was minimum at 280 kg after 12 days of irrigation (soil moisture 8.31 per cent) for sandy loam and that for clay loam soil was 310 kg after 12 days of irrigation (soil moisture 11.32 per cent). The maximum harvesting efficiency of 98.5 and 98.0 per cent were recorded after 7 days of irrigation in both type of soil at mean soil moisture level of 9.7 and 15.98 per cent (d.b) respectively.
3. The average soil bulk density was 1.466 and 1.563 gcm^{-3} respectively for sandy loam and clay loam soils.
4. The mean soil cone indices for the clay loam soil were 1.50, 1.86 and 2.41 kgcm^{-2} at 0 to 100 mm soil depth; 3.51, 3.89 and 4.19 kgcm^{-2} at 100 to 150 mm soil depth and 4.89, 5.31 and 5.70 kgcm^{-2} at 150 to 200 mm soil depth at soil moisture levels of 24, 16 and 12 per cent (d.b) respectively.

5. The mean plant population per square metre was 12.55, 11.46 and 8.53 for Erode, Salem and BSR-I varieties respectively.
6. The rhizome spread in the soil laterally was maximum 260, 280 and 300 mm for Erode, Salem and BSR-I varieties respectively and the corresponding maximum vertical spread was 185, 200 and 170 mm.
7. The mean values of weight of turmeric rhizome clump were 654, 757 and 457 g with soil for Erode, Salem and BSR-I varieties respectively and the corresponding values for the clump without soil were 225, 261, 296 g respectively.
8. The average values of moisture content of turmeric rhizome at time of harvest were 73.8, 75.6 and 71.0 per cent (d.b) for Erode, Salem and BSR-I varieties respectively.
9. The mean number of fingers per hill was 2, 7.7 and 14.8 mother rhizome, primary fingers and secondary fingers respectively for Erode variety and the corresponding values for Salem variety were 1.6, 5.7 and 11.7 and for BSR-I variety were 2.4, 9.0 and 17.5.
10. The average bulk density of turmeric rhizome at time of harvest was 984.6, 1126.6 and 1168.4 kgm^{-3} for Erode, Salem and BSR-I varieties respectively.
11. 20 deg rake angle recorded the maximum harvesting efficiency of 94.38 per cent (mean value) and was superior to 15 and 25 deg significantly.

12. The crescent shaped tool gave maximum harvesting efficiency of 93.92 per cent (mean) significantly better than straight and inverted V shaped tools.
13. The lift rod length of 250 mm showed the highest harvesting efficiency (mean) of 92.50 per cent.
14. The lift rod angle of 5 deg gave maximum harvesting efficiency of 92.71 per cent (mean) significantly higher than the other lift rod angles studied.
15. Interaction and combined effects of different tool variable combinations on harvesting efficiency were statistically analysed and the maximum harvesting efficiency was achieved with crescent shaped blade at 20 deg rake angle, 250 mm lift rod length and 5 deg lift rod angle.
16. The relationships derived by multiple linear regression analysis between harvesting efficiency (Y) as dependent variable and lift rod angle (X_1), lift rod length (X_2) and rake angle (X_3) as independent variables for each tool shape are given below.

$$Y = 86.881 - 0.01 (X_1) - 0.02 (X_2) + 0.3 (X_3)$$

for straight tool with $R^2 = 0.51$

$$Y = 88.639 - 0.03 (X_1) - 0.02 (X_2) + 0.3 (X_3)$$

for crescent tool with $R^2 = 0.73$

$$Y = 85.601 - 0.01 (X_1) - 0.004 (X_2) + 0.3 (X_3)$$

for inverted V tool with $R^2 = 0.76$

The R^2 values indicated that selected variables were sufficient to predict the harvesting efficiency for each of blade.

17. The main effect of each factor namely tool shape, rake angle, lift rod length and lift rod angle were highly significant at 1 per cent level for draft. The draft increased with rake angle, lift rod length and lift rod angle and it changed significantly with different tool shapes.
18. The tool variable combination of inverted V shaped tool with 15 deg rake angle, 150 mm lift rod length and -5 deg lift rod angle required the minimum draft of 227.7 kg and the best combination of crescent shaped blade with 20 deg rake angle, 250 mm lift rod length and 5 deg lift rod angle for maximum harvesting efficiency, recorded the draft of 315.7 kg.
19. The multiple linear regression analysis on draft (Y) as dependent variable and lift rod angle (X_1), lift rod length (X_2) and rake angle (X_3) as independent variables for each tool shape was done and the regression equations obtained for the blade were,

$$Y = 173.0 + 2 (X_1) + 2 (X_2) + 8 (X_3)$$

with $R^2 = 0.86$ for straight blade,

$$Y = 132.2 + 2 (X_1) + 2 (X_2) + 7 (X_3)$$

with $R^2 = 0.93$ for crescent blade and

$$Y = 136.3 + 2 (X_1) + 2 (X_2) + 5 (X_3)$$

with $R^2 = 0.86$ for inverted T shaped blade.

The higher R^2 values indicated that selected variables were sufficient to predict the draft required.

20. The main effect of each factor namely tool shape, rake angle, lift rod length and lift rod angles were significant at 1 per cent level indicating that each factor was influencing the damage caused to the rhizome. The damage reduced with increase in rake angle and increase in lift rod length and varied significantly with different tool shapes and lift rod angles.
21. The interaction effects of all the factor combinations indicated that crescent shaped tool with 5 deg lift rod angle, lift rod length of 250 mm and rake angles of 20 and 25 deg caused minimum damage, 20 deg rake angle recording the least damage of 2.42 per cent.
22. The multiple linear regression analysis for damages to rhizomes gave the regression equations as

$$Y = 12.213 + 0.01 (X_1) + 0.00001 (X_2) - 0.3 (X_3)$$

at $R^2 = 0.94$ for straight blade,

$$Y = 8.538 + 0.002 (X_1) + 0.003 (X_2) - 0.3 (X_3)$$

at $R^2 = 0.72$ for crescent shaped blade

$$Y = 20.002 + 0.001 (X_1) + 0.03 (X_2) - 0.05 (X_3)$$

at $R^2 = 0.87$ for inverted V shaped tool

The higher R^2 values indicated the significance of the selected variables for prediction of damage caused to rhizomes.

23. Comparing all possible combinations of tool variables, it was concluded that the combination of $T_2A_2L_2M_2$ namely crescent shaped tool with rake angle of 20 deg, lift rod length of 250 mm and lift rod angle of 5 deg was the best and

optimum parameter combination with harvesting efficiency of 97.6 per cent, damage of 2.42 per cent and draft requirement of 315.7 kg.

24. The field evaluation trials of the prototype harvester with variable tool parameters at the optimised levels in sandy loam and clay loam soils and with Erode, Salem and BSR-I varieties of turmeric gave the following performance. The effective field capacity was 0.191 to 0.197 ha per hr, harvesting efficiency was 97.26 to 97.66 per cent and the damage caused to rhizome was 2.33 to 2.90 per cent.
25. The studies with manual harvesting showed the harvesting efficiency of 87.93 per cent with damage to rhizome being 8.21 per cent.
26. The cost economics study showed that the cost of harvesting per ha was Rs.5512 with the prototype harvester while it was Rs.7480 with manual harvesting (including Rs.5000 to 5240 required for picking and removing soil from harvested crop by woman labour). The savings in cost was 26.3 per cent by harvesting with mechanical harvester over manual harvesting.
27. The break even point was 47 ha per annum and the pay back period was 3.62 years for the tractor drawn turmeric harvester.
28. It is concluded from the above studies that the mechanical harvesting of turmeric is superior to manual harvesting in terms of (i) improved harvesting efficiency of 97.26 to 97.66 per cent over 87.93 per cent; (ii) reduced damage to the crop of 2.33 to 2.90 per cent over 8.21 per cent and (iii) savings in cost by 26.3 per cent. The improved harvesting efficiency would enable the farmer

by 26.3 per cent. The improved harvesting efficiency would enable the farmer to realise additional 9 to 10 per cent of the yield and reduce the extent of damage by about 6 per cent.

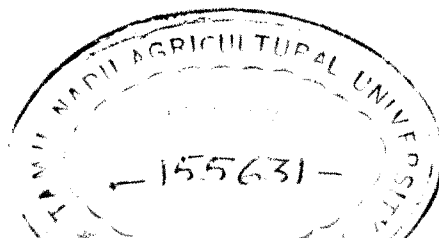
Suggestions for future work

The major portion in the cost of harvesting, in both mechanical and manual harvesting, was used for picking and separating the harvested crop which was about Rs.5000 to 5240 per ha. Therefore it is suggested that a pick up, oscillating and conveyor arrangement may be provided at the rear of the digger blade to reduce the amount of soil handled by the machine and to collect the harvested crop separately, thus reducing the labour involved for collecting the produce. This will be feasible as sufficient power will be available in the tractor PTO.

REFERENCES

REFERENCES

- Abrams, C.F., E.G.Humphries, D.D.Hamann and L.G.Wilson. 1978. Bulk harvest and handling of fresh market sweet potatoes. Trans. ASAE 1978: 15-19.
- Ahamad, D. 1984. Mechanization of peanut harvesting in Malaysia. AMA 15(2): 40-48.
- Ali, N., S.K.Patra and R.Lall. 1979. Catalogue of improved agrl. implements and equipments of India. CIAE, Bhopal.
- Anonymous. 1974. Proceedings of XVIII Annual workshop on AICRP on Farm Implements and Machinery held at Ludhiana, IARI, New Delhi.
- Anonymous. 1983. Test code and Procedure for harvesting machines, ESCAPE-RNAM, Pasay city, Philippines.
- Anonymous. 1990. Mechanical planting and harvesting of cassava and turmeric. Farm Equipment International, July/August 1990: 8.
- Anonymous. 1994. Design Data Hand Book. Faculty of Mechanical Engineering, PSG College of Technology, Coimbatore.
- Awadhwal, N.K., T.Takenaga and M.M.Babu. 1995. Development of a chisel digger for harvesting groundnut. Agric. Engg. J. 4(4): 207-215.
- Bindu, U.B., and J.Kilgaur. 1994. Groundnut harvesting machine for Northern Nigeria. AMA 25(1): 33-36.
- Bosoi, E.S., O.V. Verniaev, I.I. Smirnov and E.G. Sultan Shakh. 1987. Theory, construction and calculations of agricultural machines. Oxonian Press Pvt. Ltd. New Delhi.
- Burkill, I.H. 1966. A dictionary of the Economic Products of Malay Penionsula. Kualalampur, Ministry of Agriculture and Co-operatives.
- Chadha, K.L., and Rethinam (Eds). 1994. Advances in Horticulture Vol.9 - plantation and spice crops - part I. Malhotra Publishing House, New Delhi.
- Chase, L.W. 1942. A study of sub surface tillage blade. Agricultural Engineering 23(1): 43-50.
- Chesson, J.H., H.Johnson, C.R.Brooks, R.G.Curley, F.P.Burkner and R.M.Perkins. 1978. Mechanical harvesting investigations for fresh market onions. Trans. ASAE 1978: 838-842.



- Dash, S.K., D.K.Das, J.C.Paul, J.N.Mishra and S.K.Swain. 1998. Development and performance evaluation of bullock drawn groundnut diggers. *AMA* 29(3): 67-70.
- Dawelbeit, M.I. 1991a. Comparison of four peanut harvesting systems in irrigated clays of sudan. *Applied Engg. in Agril.* 7(1): 10-11.
- Dawelbeit, M.I. 1991b. Design and testing of a vibratory groundnut digger. *Proc. of International Agril. Mechanization conference held in beijing, China.* 16-20 October 1991. 4-327.
- Dawelbeit, M.I. 1992. Effect of plant orientation in the windrow on groundnut combining losses in irrigated clay soils of the Sudan. *AMA* 23(4): 50-52.
- Dawelbeit, M.I. 1993. Effect of mechanical shaking of groundnut on combining losses in heavy clay soils of Sudam. *AMA* 24(2): 51-53.
- Divis. J., and Z.Sterba. 1997. Relationship of fertilization and mechanical damage to potato tubers in krasa cultivar. *Rostlinna Vyroba - UZPI (Czech Republic)* 43(4): 199-204.*
- Divakar Durairaj, C. 1995. Investigations of dynamic behaviour of tool and operational parameters in relation to design of bent leg plough. Unpublished Ph.D. Thesis. Tamil Nadu Agricultural University, Coimbatore.
- Duraisamy, V.M. 1997. Investigations on the effect of soil, crop, machine and operational parameters in relation to mechanical harvesting of groundnut. Unpub Ph.D. thesis. Tamil Nadu Agril. University, Coimbatore.
- Duraisamy, V.M., M.Balasubramanian and R.Manian. 1998. Performance of tractor drawn groundnut harvesting tools. Pap. presented in National Convention of Agricultural Engineers, Institution of Engineers, Coimbatore, December 1998.
- Edison, S., A.K.Johny, K.Nirmal babu and A.Ramadasan. 1991. Spices Varieties. National Research Centre for Spices. Calicut.
- Fontaine, E.R. 1954. Investigation into the mechanisation of soil adhesion. *Journal soil science.* 5(2): 251-263.
- Garg. I.K., A.K.Madan, and Santokh Singh. 1990. Performance evaluation of tractor operated groundnut diggers. *J. of Research of Punjab Agril. Univ.* 23(4): 645-651.
- Ghanshyam Das and Avinash Agarwal. 1985. Simple attachments to Indian Country Plough. *AMA* 16(2): 30-33.

- Gill, W.R., and G.E.Vanden Berg. 1967. Soil dynamics in tillage and traction. USDA Handbook No.316. USDA Washington: 255-258.
- Godwin, R.J., and G.Spoor. 1977. Soil failure with narrow blades. J. Agrl. Engg. Res. 22(4): 213-228.
- Govindarajan, V.S. 1980. Turmeric - Chemistry, Technology and Quality. CRC critical reviews on Food and Nutrition. 12(3): 199-301.
- Grisso, R.D., J.V.Perumpral and C.S.Desai. 1980. A soil-tool interaction model for narrow tillage tools. ASAE Winter meeting, paper No.80-518. American Society of Agrl. Engineers, Michigan, USA.
- Guelle, C.E. 1946. A new sugar beet harvester. Agric. Engg. 27(12): 550-553.
- Gupta R.K. and R.P. Kachru. 1992. Turmeric physical properties of Turmeric rhizomes and Powder. Spicesdnetia 5(9): 7.
- Hardy, E.A. 1938. Tillage in relation to weed root systems. Agricultural Engineering 19: 435-438.
- Harrison, H.P. 1982. Soil reactions from laboratory studies with an inclined blade. Trans. ASAE 25(1): 7-12, 17.
- Havard, M. 1985. Mechanical harvesting of groundnut in senegal. Mechinisme Agricole Tropical, Centre de Bombay, Senegal 92: 31-40.*
- Hettiaratchi, D.R.P., B.D.Whitny and A.R.Reece. 1966. The calculation of passive pressure in two-dimensional soil failure. J.Agrl. Engg. Res. 11(2): 89-107.
- Hettriaratchi, D.R.P., and A.R.Reece. 1974. The calculation of passive soil resistance, Geotechnique 24(3): 289-310.
- Jadhav, R.V., P.A.Turbatmath and L.V.Gharte. 1995. Design, development and performance evaluation of onion digger winower. AMA 26(3): 35-38.
- James R.Hammerle. 1970. Design of sweet potato machinery. Trans. ASAE 1970: 281-285.
- Kaburaki, H., and M.Kisu. 1959. Studies on cutting characteristics of plough. Transaction No. 79. Journal of Kanto-Tonsan, Agrl. Expt. Stn. NIAE (USA).*
- Kang, W.S., and J.L.Halderson. 1991. A vibratory two row potato digger. Appl. Eng. Agri. St Joseph Mich. ASAE Nov. 1991, 7(6): 683-687.
- Kawamura, N. 1952. Study on soil cutting and pulverization. Soc. Agrl. Mach. J. (Japan). 14(3): 65-71.*

- Kepner, R.A., R.Bainer, E.L.Barger. 1987. Principles of Farm Machinery. CBS Publishers and Distributors, New Delhi.
- Klenin, N.I., I.F.Popor and V.A.Sakun. 1985. Agricultural Machines. Amerind Publishing Co. Pvt. Ltd., New Delhi.
- Krishnamoorthy, M.N., R.Padma Bai, C.P.Natarajan and S.Kuppuswamy. 1975. Colour content of turmeric varieties and studies of its processing. J.Food. Sec. Technol. (India), 12: 12-14.
- Kumar, N., J.B.M. Md.Abdul Khader, P.Rangaswami and I.Irulappan. 1997. Introduction to spices, plantation crops, medicinal and aromatic plants. Oxford & IBH Publishing Co.Pvt. Ltd. New Delhi.
- Kushwaha, R.L., L.Chi and J.Shen. 1993. Analytical and numerical models for predicting soil forces on narrow tillage tools - A review. Canadian Agricultural Engg. 35(3): 183-192.
- Liang, L.S., J.R.Tsay, S.R.Yen and T.H.Chow. 1989. Study on the once over peanut harvester. J.Agrl. Research of China 38(1): 104-126.*
- Luth, H.J., and R.D.Wismer. 1971. Performance of plane soil cutting blades in sand. Trans. ASAE 14: 255-259, 262.
- Maraviya, R.B., D.K.Mathur and P.N.Sarsavadia. 1988. Groundnut digger suitable for Udaipur region. Agrl. Engg. Today 12(2): 4-5, 21.
- Mathai, C.K. 1976. Variability in turmeric oil and curcumin. Quali. Plant-Pl. Fds. Hum. Nutr. 25: 227-230.
- McKyes, E., and O.S.Ali. 1977. The cutting of soil by narrow blades. Journal of Terramechanics 14(2): 43-58.
- McLeod, C.D., G.C.Misener and J.R.Caissie. 1989. A vertical lift digger for harvesting potatoes. Can.Agric. Eng. 31:11-14.
- Michael O'Brien and R.W.Scheuerman. 1969. Mechanical harvesting, handling and storing of sweet potatoes. Trans. ASAE 1969: 261-263.
- Misener, G.C., C.D.Mc Leod, and L.P.Mcmillan. 1984. Evaluation of a prototype potato harvester. Trans. ASAE 1984: 24-28.
- Mizrach, A., A.Margolin, R.Feller and Y.Alper. 1983. Peanut salvage machine for sandy loam and clay loam soils. Trans. ASAE 26(2): 389-391.
- Murugesan, V., and A.Tajuddin. 1995. Digger for turmeric harvesting - a field experience. Agric. Engng. Today 19(1-2): 51-56.

- Narayanan, C.S., K.Rajaraman, B.Sankari Kutty, M.A. Sumathi Kutty and A.G.Mathew. 1982. Colouring principle of turmeric. p 176-181. Ginger and turmeric - Proc. National Seminar. CPCRI. Kasaragod.
- Odigboh, E.V., and S.F.Ahmed. 1982. A cassava harvester - Design analysis and prototype development. AMA Summer 1982: 40-48.
- Osman, M.S. 1964. The mechanics of soil cutting blades. J. Agrl. Engg. Res. 9(4): 313-328.
- Parmar, R.S., R.W.Meclendon and E.J.Williams. 1994. A computer simulation model for peanut machinery management. Applied Engineering in Agriculture 10(4): 455-461.
- Payne, P.C.J. 1956. The relationship between the mechanical properties of soil and the performance of simple cultivating implements. Journal of Agricultural Engg. Research 1(1): 23-50.
- Payne, P.C.J., and D.W.Tanner. 1959. Relationship between rake angle and the performance of simple cultivation implements. J. of Agrl. Engg. Research 4(4): 312-325.
- Perumpral, J.V., R.D.Grisso and C.S.Desai. 1983. A soil-tool model based on limit equilibrium analysis. Trans. ASAE 26(4): 991-995.
- Peterson, C.L., R.E.Thornton and D.A.Smittle. 1975. Potato harvester evaluations. Trans. ASAE : 240-245.
- Pratap Singh and K.P.Pandey. 1981. Soil separation by and Power requirement of a potato elevator digger. AMA Summer 1981: 27-29.
- Prochazka, J. 1967. Force relationship and power requirements of beet shares. J.Agric. Engg. Res. 12(2): 152-170.
- Pruthi, J.S. 1993. Major spices of India - Crop Management and Post Harvest Technology. Indian Council of Agrl. Research, New Delhi.
- Rama Rao, M., K.Rama Chenna Reddy and M.Subbarayudu. 1975. Promising turmeric types of Andhra Pradesh. Indian spices 12: 12-5.
- Ruiz, A. and J.Oretiz Convate. 1975. Study of the mechanical properties of groundnut influencing the adaptation of cultivars to mechanical harvesting. Technologia Agraria. 2:25-54.
- Ros, V., R.J.Smith, S.J.Marley and D.C.Erbach. 1995. Mathematical modelling and computer aided design of passive tillage tools. Trans. ASAE 38(3): 675-683.

- Sandeep Mann and Sudhama Agarwal. 1998. Performance evaluation of potato digger as an onion digger. Pap. presented at National Conventional Agri. Engineers Institute of Engineers, Coimbatore December, 1998.
- Sastri, B.N. 1950. The Wealth of India. Raw materials vol.2, New Delhi. CSIR. 402-405.
- Savani, J.B., A.H.Memom, P.M.Singh and L.P.Singh. 1983. Development and evaluation of a bullock drawn groundnut digger ISAE paper 83-1402. ISAE, New Delhi.
- Sharma, A.P., and S.R.Verma. 1986a. Performance and vibration control of tractor mounted oscillatory potato digger. AMA 17(1): 47-50.
- Sharma, A.P., and S.R.Verma. 1986b. Design, development and field evaluation of an oscillatory potato digger. AMA 17(3): 60-62.
- Sivaraman, K. 1992. Studies on productivity of turmeric - maize and onion intercropping systems. Unpub Ph.D thesis. Tamil Nadu Agri. University. Coimbatore.
- Smith, H.P. 1968. Farm Machinery and Equipment. Mc-Graw Hill and Company Inc. London.
- Srivastava, N.S.L., and R.N.S.Yadav. 1978. Mechanizing sugar beet cultivation in India. The Agricultural Engineer 21: 35-38.
- Stafford, J.V., and D.W.Tanner. 1983. Effect of rate on soil shear strength and soil metal friction - shear strength. Soil and Tillage Research 3(3): 245-260.
- Stokes, C.M., and I.F. Reed. 1950. Mechanisation of peanut harvesting in Alabama. Agri. Engg. 31: 175-177.
- Tarachandra Thakur, Raj Deo Singh and Bachchan Singh. 1980. Development and evaluation of simple tractor mounted digger for sugar beet. AMA Spring 1980: 72-76.
- Thomas, R.J., R.E.Petti, R.A.Taber and B.C.Jones. 1983. Peanut Pod strength. Peanut Science 10(2): 97-101.
- Urschel, W.E. 1946. A sugar beet combine. Agric. Engg. 29(11): 480.
- Vedak, B.S., and J.H.Young. 1976. Simulation of peanut harvesting systems. Trans. ASAE paper No.74-1022: 244-248.
- Wayne Lepori and Price Hobgood. 1970. Mechanical harvester for fresh market onions. Trans. ASAE 1970: 517-522.

White, P.H., and R.C.Roy. 1982. A once-over peanut harvester. Proc. American Peanut Research and Education Society Inc. Canada 14(1): 116.*

Wulfsohn, D., B.A. Adams and D.G. Fredlund. 1996. Application of unsaturated soil mechanics for agricultural conditions. Canadian Agrl. Engg. 38(3): 173-181

Yang Ren Hwang. 1983. Development of peanut combine harvester. AMA 14(2): 11-16.

Zoz, F.M. 1974. Optimum width and speed for least cost tillage operations. Transactions of ASAE. 17(3): 845-850.

*** original not seen.**

ANNEXURES

ANNEXURE I

Soil moisture at harvest time, per cent (db)

Red sandy loam			Clay loam		
moisture level 1	moisture level 2	moisture level 3	moisture level 1	moisture level 2	moisture level 3
14.01	10.02	7.70	23.05	15.90	11.61
14.25	9.96	7.90	24.10	16.32	12.42
15.30	9.61	8.40	22.98	15.80	12.86
14.61	9.33	8.35	24.36	16.10	11.20
14.82	9.46	8.70	23.87	16.30	11.41
15.25	9.99	8.61	24.80	15.79	12.10
14.71	9.70	8.25	23.75	15.01	11.69
14.92	10.05	7.95	24.25	15.95	12.10
14.37	9.21	8.81	24.60	16.70	12.05
14.51	9.66	8.63	24.05	15.98	11.80

ANNEXURE II

Bulk density values, gcm³

Red sandy loam M.C. 14.7%	Clay loam M.C. 15.6%
1.51	1.58
1.48	1.62
1.52	1.56
1.40	1.66
1.42	1.58
1.45	1.56

ANNEXURE III

Cone Index values, gcm^{-2}

Clay loam								
Depth 0-10			Depth 10-15			Depth 15-20		
M.C level	M.C level	M.C level	M.C level	M.C level	M.C level	M.C level	M.C level	M.C level
1	2	3	1	2	3	1	2	3
1.4	1.9	2.4	3.45	3.85	4.10	4.45	5.30	5.7
1.45	2.0	2.35	3.50	3.90	4.15	4.70	5.25	5.75
1.65	1.85	2.45	3.85	3.85	4.2	4.80	5.35	5.65
1.55	1.85	2.40	3.45	3.95	4.2	5.00	5.35	5.80
1.35	1.80	2.55	3.60	4.00	4.25	5.05	5.20	5.70
1.70	1.90	2.24	3.50	3.90	4.20	5.10	5.15	5.65
1.65	1.85	2.35	3.55	3.90	4.25	4.90	5.40	5.65
1.40	1.90	2.40	3.40	3.85	4.10	4.95	5.35	5.75
1.40	1.75	2.45	3.45	3.85	4.20	4.95	5.35	5.70
1.45	1.80	2.35	3.60	3.8	4.20	4.85	5.35	5.60

ANNEXURE IV

Plant population of crop varieties, No. per m^2

Erode	Salem	BSR - I
11.8	12.0	8.3
12.6	11.8	8.9
12.5	11.5	8.4
12.6	11.5	8.6
12.8	11.0	9.0
13.0	11.0	8.0

ANNEXURE V

Rhizome spread of crop varieties

Erode		Salem		BSR - I	
Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
b	d	b	d	b	d
25	18	27	20	28	15.5
24	18	26	19	29	16
20	17	25	18.5	30	16.5
26	18	24	20	27	17
24	18.5	26	18.5	28	16.5
25	18	25	19	--	--

ANNEXURE VI

Weight of rhizomes at time of harvest, gms

Erode		Salem		BSR - I	
With soil	Without soil	With soil	Without soil	With soil	Without soil
650	225	700	250	450	300
640	220	720	240	440	290
670	235	750	260	450	292
635	220	780	265	460	305
630	210	800	280	460	280
700	240	790	270	480	310

ANNEXURE VII

Moisture content of rhizomes at harvest, % db

Erode	Salem	BSR - I
71.0	75.2	70.1
73.3	74.6	71.0
75.6	77.3	70.6
74.3	74.8	70.8
76.4	75.6	71.2

ANNEXURE VIII

No. of fingers / rhizomes per plant

Erode			Salem			BSR - I		
Mother rhizome	Primary fingers	Secondary fingers	Mother rhizome	Primary fingers	Secondary fingers	Mother rhizome	Primary fingers	Secondary fingers
2	8	15	1	6	12	2	10	20
2	9	17	1	6	12	2	8	16
2	8	1	2	6	13	3	10	17
2	8	14	2	6	12	2	9	18
2	7	12	1	7	11	3	10	20
2	8	15	2	5	10	2	8	15
2	7	14	2	6	11	3	9	17
2	7	14	2	5	9	2	8	17
2	8	16	2	5	10	3	10	19
2	7	15	1	6	11	2	8	16

ANNEXURE IX

Bulk density of fingers / rhizomes at harvest, kg / m³

Erode	Salem	BSR - I
970	1100	1150
987	1150	1175
997	1078	1177
1001	1145	1160
968	1160	1180

ANNEXURE X

Multiple linear regression analysis for harvesting efficiency - straight blade

VARIANCE-COVARIANCE MATRIX

	Y	X ₁	X ₂	X ₃
Y	2.826654	-.6673073	-1.397307	5.217884
X ₁	-.6673076	69.23076	.0000000	.0000000
X ₂	-1.397307	.0000000	69.23076	.0000000
X ₃	5.217884	.0000000	.0000000	17.30769

CORRELATION MATRIX

	Y	X ₁	X ₂	X ₃
Y	1.000	-0.048	-0.100	0.746
X ₁	-0.048	1.000	0.000	0.000
X ₂	-0.100	0.000	1.000	0.000
X ₃	0.746	0.000	0.000	1.000

INVERSE MATRIX

	X ₁	X ₂	X ₃
X ₁	.000555556	.000000000	.000000000
X ₂	.000000000	.000555556	.000000000
X ₃	.000000000	.000000000	.002222220

REGRESSION EQUATION

$$Y = 86.881 - 0.01 (X_1) - 0.02 (X_2) + 0.3 (X_3)$$

$$R^2 = .67$$

$$R^2 (\text{ADJUSTED FOR DF}) = .61$$

	COEFFICIENT	STANDARD ERROR	T-TEST
[X ₁]	-0.00963889	.027668051	-0.35
[X ₂]	-0.02018333	.027668051	-0.73
[X ₃]	0.30147751	.055336077	5.45

ANNEXURE XI

Multiple linear regression analysis for harvesting efficiency - crescent blade

VARIANCE-COVARIANCE MATRIX

	Y	X ₁	X ₂	X ₃
Y	5.110618	-1.974615	-1.500000	5.166346
X ₁	-1.974615	69.23076	.0000000	.0000000
X ₂	-1.500000	.0000000	69.2307692	.0000000
X ₃	5.166346	.0000000	.0000000	17.30769

CORRELATION MATRIX

	Y	X ₁	X ₂	X ₃
Y	1.000	-1.105	-0.080	0.549
X ₁	-1.105	1.000	0.000	0.000
X ₂	-0.080	0.000	1.000	0.000
X ₃	0.549	0.000	0.000	1.000

INVERSE MATRIX

	X ₁	X ₂	X ₃
X ₁	.000555556	.000000000	.000000000
X ₂	.000000000	.000555556	.000000000
X ₃	.000000000	.000000000	.002222220

REGRESSION EQUATION

$$Y = 88.639 - 0.03 (X_1) - 0.02 (X_2) + 0.3 (X_3)$$

$$R^2 = .82$$

$$R^2 \text{ (ADJUSTED FOR DF)} = .73$$

	COEFFICIENT	STANDARD ERROR	T-TEST
[X ₁]	-0.00963889	.027668051	-0.35
[X ₂]	-0.02018333	.027668051	-0.73
[X ₃]	0.30147751	.055336077	5.45

ANNEXURE XII

Multiple linear regression analysis for harvesting efficiency - inverted-V blade

VARIANCE-COVARIANCE MATRIX

	Y	X ₁	X ₂	X ₃
Y	3.447333	-.6157692	.2950000	4.545192
X ₁	-.6157692	69.23076	.0000000	.0000000
X ₂	.2950000	.0000000	69.23076	.0000000
X ₃	4.545192	.0000000	.0000000	17.30769

CORRELATION MATRIX

	Y	X ₁	X ₂	X ₃
Y	1.000	-0.040	0.019	0.588
X ₁	-0.040	1.000	0.000	0.000
X ₂	0.019	0.000	1.000	0.000
X ₃	0.588	0.000	0.000	1.000

INVERSE MATRIX

	X ₁	X ₂	X ₃
X ₁	.000555556	.000000000	.000000000
X ₂	.000000000	.000555556	.000000000
X ₃	.000000000	.000000000	.002222220

REGRESSION EQUATION

$$Y = 85.601 - 0.01 (X_1) + 0.004 (X_2) + 0.3 (X_3)$$

$$R^2 = .85$$

$$R^2 \text{ (ADJUSTED FOR DF)} = .76$$

	COEFFICIENT	STANDARD ERROR	T-TEST
[X ₁]	-0.00889444	.037565258	-0.24
[X ₂]	0.00426111	.037565258	0.11
[X ₃]	0.26261088	.075130483	3.50

ANNEXURE XIII

Multiple linear regression analysis for draft - straight blade

VARIANCE-COVARIANCE MATRIX

	Y	X ₁	X ₂	X ₃
Y	2029.395	127.3846	171.9615	139.5576
X ₁	127.3846	69.23076	.0000000	.0000000
X ₂	171.9615	.0000000	69.23076	.0000000
X ₃	139.5576	.0000000	.0000000	17.30769

CORRELATION MATRIX

	Y	X ₁	X ₂	X ₃
Y	1.000	0.340	0.459	0.745
X ₁	0.340	1.000	0.000	0.000
X ₂	0.459	0.000	1.000	0.000
X ₃	0.745	0.000	0.000	1.000

INVERSE MATRIX

	X ₁	X ₂	X ₃
X ₁	.000555556	.000000000	.000000000
X ₂	.000000000	.000555556	.000000000
X ₃	.000000000	.000000000	.002222220

REGRESSION EQUATION

$$Y = 173.0 + 2 (X_1) + 2 (X_2) + 8 (X_3)$$

$$R^2 = .88$$

$$R^2 (\text{ADJUSTED FOR DF}) = .86$$

	COEFFICIENT	STANDARD ERROR	T-TEST
[X ₁]	1.84000000	.390310270	4.71
[X ₂]	2.48388889	.390310270	6.36
[X ₃]	8.06332622	.780620196	10.33

ANNEXURE XIV

Multiple linear regression analysis for draft - crescent blade

VARIANCE-COVARIANCE MATRIX

	Y	X ₁	X ₂	X ₃
Y	1413.653	129.7692	150.346	114.6346
X ₁	129.7692	69.23076	.0000000	.0000000
X ₂	150.3461	.0000000	69.23076	.0000000
X ₃	114.6346	.0000000	.0000000	17.30769

CORRELATION MATRIX

	Y	X ₁	X ₂	X ₃
Y	1.000	0.415	0.481	0.733
X ₁	0.415	1.000	0.000	0.000
X ₂	0.481	0.000	1.000	0.000
X ₃	0.733	0.000	0.000	1.000

INVERSE MATRIX

	X ₁	X ₂	X ₃
X ₁	.000555556	.000000000	.000000000
X ₂	.000000000	.000555556	.000000000
X ₃	.000000000	.000000000	.002222220

REGRESSION EQUATION

$$Y = 132.2 + 2 (X_1) + 2 (X_2) + 7 (X_3)$$

$$R^2 = .94$$

$$R^2 \text{ (ADJUSTED FOR DF)} = .93$$

	COEFFICIENT	STANDARD ERROR	T-TEST
[X ₁]	1.87444444	.230560048	8.13
[X ₂]	2.17166667	.230560048	9.42
[X ₃]	6.62332749	.461119892	14.36

ANNEXURE XV

Multiple linear regression analysis for draft - inverted-V blade

VARIANCE-COVARIANCE MATRIX

	Y	X ₁	X ₂	X ₃
Y	940.2316	107.0384	149.3846	85.11538
X ₁	107.0384	69.23076	.0000000	.0000000
X ₂	149.3846	.0000000	69.23076	.0000000
X ₃	85.11538	.0000000	.0000000	17.30769

CORRELATION MATRIX

	Y	X ₁	X ₂	X ₃
Y	1.000	0.420	0.586	0.667
X ₁	0.420	1.000	0.000	0.000
X ₂	0.586	0.000	1.000	0.000
X ₃	0.667	0.000	0.000	1.000

INVERSE MATRIX

	X ₁	X ₂	X ₃
X ₁	.000555556	.000000000	.000000000
X ₂	.000000000	.000555556	.000000000
X ₃	.000000000	.000000000	.002222220

REGRESSION EQUATION

$$Y = 136.3 + 2 (X_1) + 2 (X_2) + 5 (X_3)$$

$$R^2 = .86$$

$$R^2 \text{ (ADJUSTED FOR DF)} = .86$$

	COEFFICIENT	STANDARD ERROR	T-TEST
[X ₁]	1.54611111	.145741005	10.61
[X ₂]	2.15777778	.145741005	14.81
[X ₃]	4.91777344	.291481881	16.87

ANNEXURE XVI

Multiple linear regression analysis for damage - straight blade

VARIANCE-COVARIANCE MATRIX

	Y	X ₁	X ₂	X ₃
Y	1.843882	.3742307	.0003846	-5.493653
X ₁	.3742307	69.23076	.0000000	.0000000
X ₂	.0003846	.0000000	69.23076	.0000000
X ₃	-5.493653	.0000000	.0000000	17.30769

CORRELATION MATRIX

	Y	X ₁	X ₂	X ₃
Y	1.000	0.033	0.019	-0.972
X ₁	0.033	1.000	0.000	0.000
X ₂	0.000	0.000	1.000	0.000
X ₃	-0.972	0.000	0.000	1.000

INVERSE MATRIX

	X ₁	X ₂	X ₃
X ₁	.000555556	.000000000	.000000000
X ₂	.000000000	.000555556	.000000000
X ₃	.000000000	.000000000	.002222220

REGRESSION EQUATION

$$Y = 12.213 + 0.01 (X_1) + 0.00001 (X_2) - 0.3 (X_3)$$

$$R^2 = .95$$

$$R^2 \text{ (ADJUSTED FOR DF)} = .94$$

	COEFFICIENT	STANDARD ERROR	T-TEST
[X ₁]	0.00540556	.007849699	0.69
[X ₂]	0.00000556	.007849699	0.00
[X ₃]	-0.31741083	.015699391	-20.22

ANNEXURE XVII

Multiple linear regression analysis for damage - crescent blade

VARIANCE-COVARIANCE MATRIX

	Y	X ₁	X ₂	X ₃
Y	1.509798	.1465384	.2096153	-4.423269
X ₁	.1465384	69.23076	.0000000	.0000000
X ₂	.2096153	.0000000	69.23076	.0000000
X ₃	-4.423269	.0000000	.0000000	17.30769

CORRELATION MATRIX

	Y	X ₁	X ₂	X ₃
Y	1.000	0.014	0.021	-0.865
X ₁	0.014	1.000	0.000	0.000
X ₂	0.021	0.000	1.000	0.000
X ₃	-0.865	0.000	0.000	1.000

INVERSE MATRIX

	X ₁	X ₂	X ₃
X ₁	.000555556	.000000000	.000000000
X ₂	.000000000	.000555556	.000000000
X ₃	.000000000	.000000000	.002222220

REGRESSION EQUATION

$$Y = 8.538 + 0.002 (X_1) + 0.003 (X_2) - 0.3 (X_3)$$

$$R^2 = .75$$

$$R^2 (\text{ADJUSTED FOR DF}) = .72$$

	COEFFICIENT	STANDARD ERROR	T-TEST
[X ₁]	0.00211667	0.15415946	0.14
[X ₂]	0.00302778	.015415946	0.20
[X ₃]	-0.25556644	.030831879	-8.29

ANNEXURE XVIII

Multiple linear regression analysis for damage - inverted-V blade

VARIANCE-COVARIANCE MATRIX

	Y	X ₁	X ₂	X ₃
Y	4.24790	.4630769	-2.168076	-8.391346
X ₁	.4630769	69.23076	.0000000	.0000000
X ₂	-2.168076	.0000000	69.23076	.0000000
X ₃	-8.391346	.0000000	.0000000	17.30769

CORRELATION MATRIX

	Y	X ₁	X ₂	X ₃
Y	1.000	0.027	-0.126	-0.979
X ₁	0.027	1.000	0.000	0.000
X ₂	-0.126	0.000	1.000	0.000
X ₃	-0.979	0.000	0.000	1.000

INVERSE MATRIX

	X ₁	X ₂	X ₃
X ₁	.000555556	.000000000	.000000000
X ₂	.000000000	.000555556	.000000000
X ₃	.000000000	.000000000	.002222220

REGRESSION EQUATION

$$Y = 20.022 + 0.01 (X_1) - 0.03 (X_2) - 0.5 (X_3)$$

$$R^2 = .87$$

$$R^2 \text{ (ADJUSTED FOR DF)} = .87$$

	COEFFICIENT	STANDARD ERROR	T-TEST
[X ₁]	0.00668889	.008212576	0.81
[X ₂]	-0.03131667	.008212576	-3.81
[X ₃]	-0.48483291	0.16425144	-29.52