DEVELOPMENT OF A MECHANICAL HARVESTER FOR *AMARANTHUS*

BY

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APPROVAL PAGE

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DEDICATION

This project is dedicated to the glory of the Almighty God for his abundant grace in my life, my wife – Tayibat, Adebukola Akande nee Baada; and to my late parents Mr. and Mrs. Akande Kolawole and also to my late friend, Adesoye Femi, may their gentle souls rest in perfect peace. Amen.

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ABSTRACT

A lot of drudgery is involved in the manual harvesting of leafy vegetables. Therefore, with small and medium scale farmers in mind, a low cost leafy vegetables harvester was developed. The major components of the machine are the frame which support the other components, chopper knives which cut the vegetable stems about 6 cm from the soil surface, set of spur gears which drives the propelling land wheels.. The machine is rugged and sturdy, and it was designed to harvest leafy vegetables such as *Amaranthus Spp*, water leaf, soko and *Solanium nigrum* (odu). The experimental machine was designed to be coupled to the tractor to hasten harvesting. However the experimental machine prototype was manually pushed to harvest the vegetable during testing, to permit monitoring of the machine performance at close range. The operating speed of the machine during harvesting was 3 km /h.

For the purpose of evaluating the performance of the harvester, a field was prepared where *amaranthus* was planted at different weeks interval. The following parameters were varied during harvesting, moisture content of the soil and age/maturity of vegetables. Prior to harvesting, two growth parameters of the *amaranthus* plant, that is stem diameter and height of crop were determined and were used for design calculation.

The result of the tests performed on machine show that it is appropriate for small farm holders. Furthermore, it shows that the Field Efficiency of the machine was influenced by moisture content of the soil and the age of crop at harvest.

The machine's maximum Field Capacity was 0.8 ha/h with a Field Efficiency of 82 %. The Quality Performance Efficiency was 60% at 22% Moisture content (wb) of the experimental soil. Harvesting was best at five weeks after planting. The cost of the machine was estimated at about ₦16,123.

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CHAPTER ONE

1. INTRODUCTION

Vegetables are grown for man and animal consumption. There are different types of vegetables. The leafy vegetables include *amaranthus*, spinach and water leaf, most of which are widely cultivated in Nigeria.

1.1 Brief History of Amaranthus

Amaranth (*Amaranthus hypochondriacus*. *A. Cruenthus* (Grain) and *A. tricolor* (Vegetable) is a plant with an upright growth habit cultivated for both its seed which are used as a grain and its leaves which are used as vegetables. Both the leaves and seeds contain protein of an unusually high quality (Bressani, 1990).

Amaranth is an ancient crop originating in the Americas. It has been cultivated for more than 8000 years, dating back at least to the Mayan civilization of South and Central America (Stallknecht and Schultz-Schaefer, 1993). It was a staple of the Aztecs and was incorporated into their religious ceremonies. In 1516, the conquistadors prohibited the growing of *amaranth Spp* in that area, today only a limited amount of *amaranthus* is grown, most of its grain (vegetable seeds) is popped and mixed with honey to make "algeria" candy (Stallknecht & Schultz – Schaeffer, 1993). The largest hectarage grown was during the height of the Aztec civilization in Mexico in the 1400's,.

(Caspell, 2002). For the past two centuries, grain and leafy *amaranth* have been grown in scattered locations, including central America, India, Nepal, China and Eastern Africa. (Kauffinan, & Weber 1990). A few thousand acres of *amaranth spp* are commercially grown in the United States, and markets for that acreage is developing each year (Grubben, 1977).

1.2 Uses of *Amaranthus*

The uses of the *amaranth Spp* include the following:

1.2.1 Food uses

Vegetable *amaranth* leaves and stems or the entire plants may be eaten raw or cooked as spinach. However, cooking and discarding the water will remove potentially harmful oxalates and nitrates.

Alternatively, seeds can be popped like popcorn. In the culture of the Rodale people, popped *amaranth* can be used in confectioneries bound with sorghum, molasses or honey, in high-energy granola and granola bars, in cheese spreads, to flavour salad dressing; in breeding for chicken as fish, in crackers, pie crust and breads, and as toppings for casseroles and deserts (Grubben, 1977) It can be used in reduction of cholesterol in laboratory animal and health and food companies (Bressani, 1990).

1.2.2 Forage uses

Little is known about the production and utilization of *amaranth spp as* forage. The leaves, stem and head are high in protein (15 – 24% on a dry matter basis). It has been reported that a on year study conducted in Minnesota on *amaranth* forage indicated a yield potential of 4 – 5 tons/acre dry matter, with crude protein of the whole plant at 19% on dry basis (Bressani, 1990)

A similar crop to grain *amaranth*, that is red root pigweed (*Amaranthus retroflexus*), has been shown to have 24% crude protein and 79% in vitro digestible dry matter. Pigweeds are known nitrate accumulators, and *amaranth* responds similarly. Vegetable *amaranths*, which are closely related, produced 30 to 60 tons/acre of silage (80% moisture) on plots in Iowa. In areas where corn silage yields are how due to moisture limitations, *amaranth spp* (leaf and grain) may become a suitable silage alternative.

1.3 Economics of Amaranthus Production

In some developed countries especially in Asia, the primary market for *amaranth spp* is the food industry, where it is used in 40 – 50 products. Famers have marketed their crop in a number of ways. Some sell the leaf or allow the plant to bring out the seed before harvest. They can therefore sell the seeds to consumers. Many of these purchasers are allergic to wheat products. Other growers sell to local or regional health food stores or restaurants. There are also a few who buy the vegetables leaf or grain from the farmers and market it to the larger health food companies.

Amaranth oil is used for the treatment of ontological disease, sclerosis, malfunctions of the brain and periferic blood circulation system, immunodeficient states, gynaecological, skin, stomach and liver diseases, wounds, bruises, bedsores, ulcers, vitamin deficiency and for disease preventive purposes (Teutonico and Knorr, 1985). In the United States, companies that have developed leafy and grain *amaranth* products include Health Valley, Natural Food, Arrow Mills, Walnut Acres, Nu – world *Amaranth* and American *Amaranth,* Inc. (Teutonico and Knorr, 1985).

1.4 Harvesting

Harvesting is the most critical stage for leafy *amaranth* production. Without careful harvest technique it is possible to damage the majority of the leaves. *Amaranth* can be harvested manually with knife, by cutting the stem when the leaves are fresh. If the grain is the interest during harvesting this one can be done when the seeds dry up. However, *amaranth* grain can be harvested with combine. If the stems and leaves are too wet, the seeds become sticky and adhere to the inside of the combine as well as the straw discharge. Shattering during the cutting process can also cause losses, in mechanical harvesting.

1.5 Objectives of Study

The objectives of the project are:

i. To design a machine to harvest *amaranthus spp,*

ii. To fabricate an experimental prototype of the machine

iii. To carry out the performance evaluation the experimental prototype.

1.6. Justification of Study

There has been increasing interest in leafy *amaranth* in the international community. A number of conferences for the promotion of the crop were held in China in 1977, 1979, and 1984 (Chemov, 1992). In 1987, an annual *amaranth spp* Conference was initiated in the people's Republic of China to bring together researchers in over 22 provinces (Gromov, 1995). Also in 1987, the University La Pampa in Argentina hosted a national conference on *amaranth spp* with papers presented by it researchers (Putnam 1990). China (Sprougis 2000) and United State Agency for International Development (USAID) sponsored *amaranth spp* project in Nigeria. All these aforementioned conferences and research were as a result of the importance of *amaranth* for man and animal.

Large scale production of vegetables is already being practiced in many parts of the country including the Osun State Ministry of Agriculture and many individuals, whereby women are employed to harvest at maturity

(OSADP, 2003). Dry season large-scale production of leafy vegetables is also being practiced and encouraged on many fadama lands in Nigeria to ensure all-year round production. Furthermore, the Federal University of Technology, Akure, has initiated research on dry season cultivation of arable crops including leafy vegetables such as *amaranthus* under different irrigation methods. Therefore, there is prospect for increased production of *amaranthus*. Consequently, mechanized harvesting of vegetables is desirable. A lot of drudgery is involved in the manual harvesting of *amaranthus*. Its harvesting is a labour intensive operation with an average requirement of over 120 man-hour per hectare (Anonymous, 1984). Therefore, there is need to device means of harvesting it mechanically to reduce time and labour involved, and to meet market demand.

CHAPTER TWO

2. LITERATURE REVIEW

The majority of leafy *amaranth* (*Amaranthus spp)* growing in the world are hand harvested. Harvesting by combine is necessary if *amaranth* grain and leafy production are to compete economically with other crops (Myers and Putnam, 1988). Harvesting of *amaranthus* is similar to the principle utilizedin the mechanical control of weeds, harvesting of hay and silage, harvesting of kenaf, harvesting bunched leafy greens and onion, topping sugar beet and a host of others. Therefore there is need to review existing methods and machines for harvesting.

2.1 Forage Harvesting

Forage crops can produce high yields of proteins and other nutrients per unit land area for our animals. Such crops include, alfalfa, *centrocema* and grasses. The systems that will harvest forage consists of five basic steps:

(a) Cutting of the forage at the appropriate state of maturity.

(b) Maceration of the forage to facilitate rapid drying and mat formation.

(c) Formation of this cohesive mats of macerated forage.

(d) Placement of the wet, intact mats onto the fields stubble and

(e) Pick up and packaging of dried forage mats.

Forage are commonly processed by traverse shearing as with a reciprocating mower or a cylindrical cutter head forage harvester. Research has shown that plant maturity, stem segment and shear rate significantly affect transverse shear properties of forages.

2.2 Hay Making Machines.

Hay harvesting was once the hardest work on the farm and in no crop has machinery been more efficient. The basic working components are the reaper and the cutter-bar. Previously, Jeremiah Builey, of Chester County, Pennsylvania had patented in 1822 a machine drawn by horses carrying a revolving wheel with six scythes, which was widely used. The inventions of Manning, Hussey, and Mccormick made the mower practicable. Hazard Knowles, an employee of the patent office, invented the hinged cutter-bar which could be lifted over an obstruction, but never patented the invention. William .F. Ketchum of Buffalo, New York, in 1844, patented the first machine intended to cut hay only, and dozens of others followed. The modern mowing machine was practically developed in the patent of Lewis Miller of Canton, Ohio, in 1858. Several times as many mowers as harvesters are sold, and for that matter, reapers without binding attachments are still manufactured.

Hay rakes and tedders seem to have developed almost of themselves. Diligent research has failed to discover any reliable information on the invention of the hay rake, through a horse rake was patented as early as 1818. Joab center of Hudson, New York, patented a machine for turning and spread hay in 1834. Mechanical hay headers have greatly reduced the amount of human labour

2.3 Kenaf Harvesting Machines.

Over the last 6000 years, since its first domestication, kenaf has consistently been hand harvested for use as a cordage crop (rope, twine, and sack cloth). When hand-harvested, the tall, cylindrical-shaped stalks were cut at or near ground level with a curved blade or machete.

In the United States, the USDA, Universities and private industry have developed an assortment of mechanical harvesters and post-harvest equipment (Ribboners and Decorticators). As a result of the USDA's initial interest in kenaf as an alternative cordage source during World War II, a tractor drawn harvester ribboner was developed. The original objective of the ribboners/decorticators was to harvest the bark for its valuable best fiber and discard the unwanted core material.

Newer ribboners/decorticators have been developed specially for the kenaf industry. The objectives are no longer to harvest only bark ribbons, but to separate and harvest the core material for other uses.

2.4 Mechanical Harvesting Aids for Bunched Leafy Greens and Onions

Leafy green vegetables, especially crops that include collards, mustard greens, turnip greens, were grown on 14,500 ha by about 2,000 farms in the U.S in 1978. The experimental machine had attachments that permitted the study of both automatic harvesting and labour harvesting. The automatic harvester was designed to dig, clean, bunch and tie the crop without assistance once it was properly adjusted. The labour harvester was designed to assist several workers and formed bunches as the crop was lifted and conveyed to them by the machine.

When hand bunching greens, two seats were located so that two workers were opposite from each other at the rear of the sorting conveyor. Each worker alternatively gathered leaves into a bunch at the sorting station, and dropped the tied bunch into a bulk bin.

2.5 Sugar - Beet Harvesting.

Work on the development of a complete sugar-beet harvester which tops, lifts and cleans the beet commenced in the early 1930's, but it was not until the late 1940's that large-scale production and the use of harvester began. Just, over twenty years later, nearly the whole of the crop was being mechanically harvested, with contrast services available in most areas, there is nothing to be said in favour of hand harvesting.

Topping mechanisms – All topping machines and topper loaders and most complete harvesters top the unlifted beet and rely on a feeler wheel, track or sledge of some kind, which is designed to run over the crowns of the beet and determined the setting of the knife or knives which cut off the top. The knife is usually directly attached to the spring loaded subframe which carries the feeler device, which aid in topping exercise (Kepner *et al.*, 1978).

Lifting and clearing machine may deal with one or more rows at a time. May be trailed or tractor mounted and may deliver the beat in windrows parallel to the work or at right angles to it.

2.6 Mechanical Control of Aquatic Weed.

The water hyacinth is a floating aquatic plant and therefore, any suitable harvester of the weed does not require any mechanism for root cutting or up-rooting (Berti *et al.*, 1996) as in some existing weeders such as the cocoa plantation weeding machine developed by Faborode and Makanjuola (1990) and the reciprocating weeder developed by Ademosun (1991).

In water bodies that are too wide for bank access, boat mounted equipment has to be used. Recent developments have been to make the handling of cut material more efficient. Since most submerged and floating weeds have a high water content, handling them is costly. Machines have to cut and collect the weed and then transport the heavy mass of vegetation and water to the shore. National Technology of Wargrave, UK, have developed a machine that removes most of the water during the collection process. It then shreds the residue and delivers it to a collection hopper located on the shore or to a hopper barge (Alan and Gee-Clough, 1987).

Tests were carried out on a prototype Natural Technology machine on Lake Victoria, Uganda, in May, 1995. The system of opposing conveyers was able to collect, compress and shred large water hyacinth plants. The jaw arrangement is being further developed to enable the harvester to collect filamentous algae and submerged plants whilst moving forward. Research on the growth of submerged weeds indicates that the plants that have been pulled take longer to regenerate than those that are cut.

2.7 Mechanical Weed Control on Terrestrial Habitat.

Removal of weeds is similar to harvesting of *amaranthus spp. Amaranthus* are equally weed when they grow in unwanted place. Mechanical weed control may involved weeding the whole crop, or it may be limited to selective inter-row weeding. In a well spaced crop planted 'on the square', a second inter-row weeding may be made at right angles to the first to cover a greater percentage of the soils surface. In addition, inter-row implements have been designed that control weeds within the crop row by directing soil along the row to cover small weeds (Cooke, 1988). Mechanical weeders range from hand tools such as the reciprocating weeder designed by Ademosun (1991b), to sophisticated tractor driven devices. These may include cultivating tools as hoes, harrows, tines and brush weeders, cutting tools like mowers and strimmers as well as implements like thistle-bars may do both. Custom-made basket or cage – wheeled weeders, with gangs of rolling wire cylinders offer another way to deal with seedling weeds in a friable soil (Bell *et al*, 1988). The mode of action, operating speeds and limitations of a number of mechanical weeding tools were reviewed by Tilleft and Hone (Al-Masson *et al*, 1993).

The choice of implement, and the timing and frequency of its use may depend on the crop and on the weed population. Some implements, such as fixed harrows, are thought more suitable for arable crops, while others like inter-row brush weeders may be considered to be more effective for horticultural use. The optimum timing for mechanical weed control is influenced by the competitive ability of the crop (Abu, 1991). A single inter-row cultivation at any time may provide excellent weed control in a crop like transplanted broccoli that rapidly develops a broad, shading leaf canopy (Colquhoun and Bellinder, 1966). Control from a single weeding may be poorer in crops like sweet corn (*Zea mays*) where early growth is low or in green beans (*Phaseolus villgaris*) where the growing season is relatively long (Holm, 1976).

2.8 Mechanical Harvesting of *Amarantus.*

Saunders and Becker (1984) reported that vegetables production is slightly decreasing in Kinki-Chugoku-Shikoku region in Japan, due to reduction in cultivating area by urbanization in the suburb cities, decrease of farmers, difficult of employing labours, and shortage of young successors. Therefore, vegetable production needs a lot of manpower and working hours to harvest and prepare. This has encouraged the engaged in a study to develop mechanized harvesting and processing technology for leaf vegetables such as spinach, produced in this region (Japan) (Kauffman and Weber, 1990)

In other studies which spanned between 1994 and 2000 the following works were done:

i. Developing harvesting technology (1994 – 1996). From April 1994 to March 1997, they confirmed the possibility of mechanized harvesting technology for spinach harvesting by 3 trial machines. However, there are some problems to establish the technology, especially the problem of quality of harvested spinach i.e, scratches breaks and cut caused by mechanical harvesting. The quality of mechanically harvested is less than that of manually harvested.

ii. Developing processing technology (1997 – 1999). From April, 1997 to December, 1999 they had advanced study to develop mechanized harvesting technology with processing functions for leaf vegetables based on research results. There were 3 processing functions discussed as follow:

   1. Cut the root of plants after digging up
   2. Remove incomplete leaves of plants and soils
   3. Store plants in a row into container.

iii. Developing a compact harvester with preparing functions powered electrically. Because the 4th trial machine mentioned in previous section got heavy by adding extra functions and also had a demand of path to travel in the bed of plants, and needed large head land space to turn at the end of bed of plants. It was planned, a new small-sized harvester with processing functions driven by electric motors powered by DC 12 V battery for car.

iv. Current study: The current studies are centred on combined system of harvesting and processing (from 2001 to now). For harvesting, hand made proto-type machine as used, while ELH-023 harvester, and spinach cleaner, type NC-300 produced by KUBOTA (a major manufacturer of agricultural machinery in Japan) are used in mechanized harvesting.

2.9 Agronomic Research and Development on *Amaranthus*

The most up-to-date summary of agronomic practices for the cultivation of *amaranth* in North America is provided in the annually revised *Amaranth* Production (Weber, 1990). The 1998 edition marked a special milestone, as it contained contributions from researchers from the University of Minnesota, the University of Nebraska and Iowa State University (Zheleznov *et al*, 1995, Krishnan *et al*, 1987)

Beginning in 1979, work was initiated in the US to develop methods for cultivating with standard farm machinery precision seeding methods were used to plant 0.5 kg/ha of seed to attain a desire plant density of 300,000 plants/ha (Tindall, 1986, Henderson, *et al*, 1993). It is possible to harvest the crop using a grain combine after a killing frost which serves to adequately dry down the plants (Shroyer *et al.*, 1990)

Farmers in the mid-West and Great plainsof the US who began to grow *amaranthus* commercially in the early 1980's did modifications to their farm equipment to minimize their initial investment. By increasing the seeding rate, they were able to plant *amaranth* with only minor modifications of existing equipment (Putnam, 1990; Myers and Putnam, 1988)

The small seeds of grain *amaranth* have presented a special challenge in producing the desired plant stand (Jamrishka, 1998). It is critical the seed be planted in finely prepared soil, shallowly planted and packed to assure good seed to soil contact. A planting depth of more than 1 cm delayed and decreased emergence, although in dry land areas, a planting depth of more than 1 cm may be necessary to obtain adequate moisture for germination (Henderson *et al.*, 1993). A seeding depth of 2.5 cm may be practical in friable soil of seeding rates are adjusted to compensate for reduced emergence associated with increased depth (James and Richard, 1975).

CHAPTER THREE

3. DESCRIPTION, DESIGN AND FABRICATION OF THE VEGETABLE HARVESTER

For the design of a machine to harvest leafy vegetables, the researcher took into consideration the previous work done by other researchers in the harvesting of spinach, topping machine for sugar beet, weeds removal machines, silage and hay harvesting, onion green harvesting and host of others. In the design, parameters, such as vegetable stems diameter, height of the crop, moisture content of the experimental plot, space within vegetable plant on the plot, were take into consideration.

3.1 Description of the Machine

The machine was designed and fabricated for leafy vegetable (such as *amaranthus spp water leaf*) harvesting. The machine consists of chopper knives, four wheels, spur gears, and frame (Figure 3.1a & b).

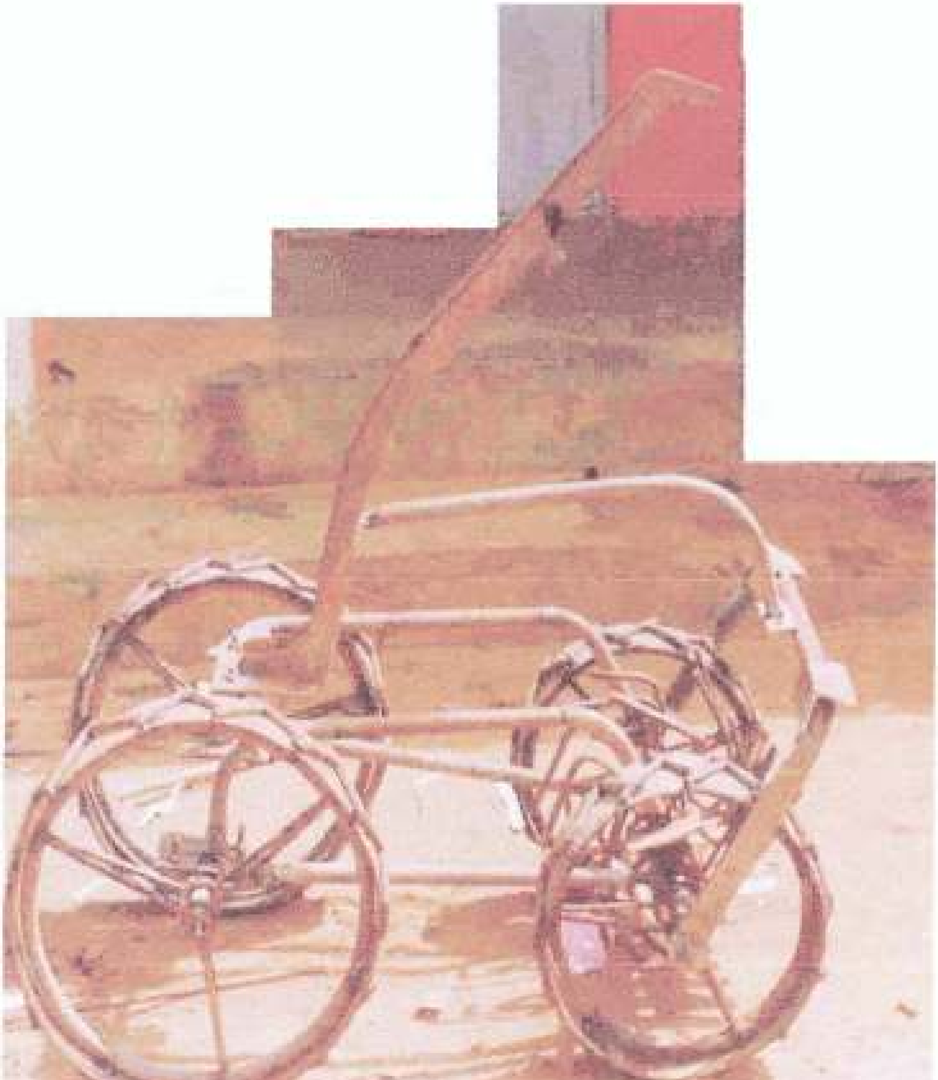


Fig. 3.1 a: Picture of the vegetable harvester

Fig. 3.2b: Amaranthus harvester mounted on a tractor

The equipment was hitched to the tractor three-point linkage. During operation, the tractor pulled the machine forward, and the chopper knives that are rotating vertically in opposite direction of the wheels, cuts the vegetables at the same time. The harvested vegetables are hand-picking at interval.

3.2 Design Considerations.

In order to ensure efficiency and reliability, the machine was designed based on the following assumptions:

i. The machine should be able to chop the vegetable stem 6 cm above the soil without uprooting the plant. This will allow for regeneration of the plant.

ii. It should reduce the labour requirement and drudgery involved in manual method of harvesting.

iii. It should harvest at a rate higher than manual methods of harvesting.

iv. The cost of the machine should be within the buying capacity of local farmers.

v. It should be simple to operate and maintain even by farmers who do not have formal education.

The following parameters were taken into consideration in the design of the machine: (i) the stem diameter of the vegetable, (ii) the height at which the vegetables would be chopped above the soil surface (6 cm,) and space between vegetables. The surface area of chopper knives was reduced (sharpen) in order that it can overcome the resistance offered by the vegetable stem during harvesting. The chopper knives also cut vegetable stem at angle 60^0 to the horizontal.

The machine was designed to have a width of cut of 30 cm on forward movement. The machine cuts vegetables 6 cm above the soil surface. The maximum diameter of *amaranthus* on average is 10 mm and height considered is 22 cm, (Table 5.1 and 5.3) was used in the design calculation.

The spur gears of the machine rotate the chopper knives in opposite direction in which the wheels are rotating, therefore allow the chopper knives to cut the vegetables.

3.3 Design Analysis

3.3.1 Power transmission system.

The machine was designed to take its power from the tractor when hitched to the three point linkage of the tractor. When the tractor moves forward, to also help in moving the mechanical harvester. In this wise, the driving gears rotate chopper knives backward to chop the vegetable. The designs of the components of the machine are described below.

3.3.2. Design of the harvester blade (chopper knives)

The chopper knives are made up of the following components.

- A shaft rotating inside two spur gears
- Two driven spur gears
- Twenty-four (24) elbow rods carrying the harvester blade.
- Eight rectangular plates made as knives.

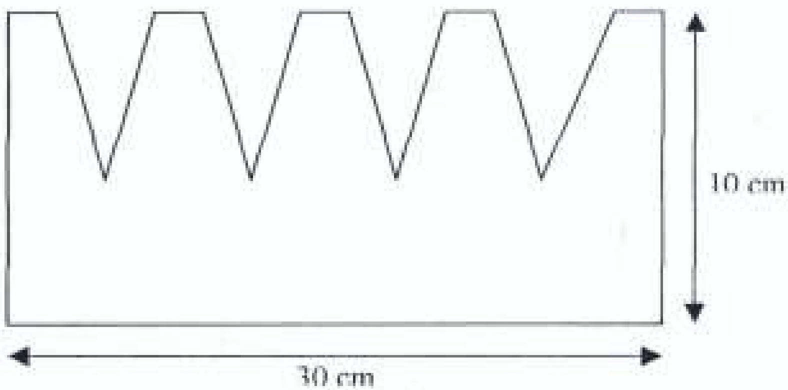


Fig. 3.2 Chopper Knife

3.3.3 Determination of the weight of the harvester blade

Weight of the harvester blade was determined by measuring the diameter of the elbow rods, the area of the plates, and their density. Their area and volume were also calculated (Appendix I).

3.3.4 Determination of the weight of the gears

The weight of the gears were calculated by measuring its diameter, the thickness and volume of the gears (the calculation is in appendix I).

3.3.5 Determination of weight of anchor for lower link.

The anchor is a circular disc. Its diameter, and volume was determine couple with its density to determine the weight of the anchor (Appendix I).

3.3.6 Determination of the number of chopper rows on the harvester shaft

The time (t) taken by the harvester to cover distance in between successive stands was calculated using

equation $$t = \frac{\pi d}{n_c}$$

This calculatuion was nthen used to determine the required number of rows of chopper. Detail calculation can be found on appendix I.

3.3.7 Design of shaft

Shaft was designed following the procedure outlined in the P.S.G Design Data (1982). See appendix I for calculation.

3.4 Design of Wheels

The machine consist of four wheels. The diameter of the front wheel is 30 cm because of the height at which vegetables will be chopped. The rear wheel is 50 cm in diameter. The width of the wheels are 10 cm. They are made of 4 mm metal plate thickness. The grip on the wheels were made of 10 mm metal rod.

3.5 Fabrication of Components and Assembly of Machine

The machine was Fabricated with locally available materials at the Agricultural Engineering workshop of Federal University of Technology Akure. During the assembly wheels were fixed with spur gears. The chopper knives are also fixed with another two spur gears, fix the wheels to the shaft with bolts and nuts. Fix the chopper knives on the wheels. Coupled to the three point linkage of the tractor (Fig 3.1)

3.6 Cost of Materials for Production of the Machine.

The cost of materials for production of the machine was calculated by adding the cost of materials, cost of machining jobs, cost of non-machining jobs together. They are shown in Tables 3.1 (A, B, C, D).

TABLE 3.1A: Cost of Materials

S/N	MATERIAL	SIZE OF PIECE	QUANTITY REQUIRED	UNIT COST ₦	AMOUNT ₦
1	Ø40 mm mild steel rod	350 mm	2000 m long	800.00 per 1 m length	1600
2	5 mm thick mild steel plate	120,000 mm^2	100 mm x 1200 mm	1,500.00 per 1	1500
3	Ø75 mil steel rod	210 mm	210 mm long	500.00 per 30 cm length	450
4	25.4 mm x 25.4 mm x 6 mm angle	8,880 mm	1½ length 9 m	800.00	2400
5	Hack saw blades		6 pieces	100.00	600
6	Electrodes		1½ packets	700.00	1050
7	Paint	1 litre	2 litres	150.00	300
8	Hollow pipe Ø 30 mm	210 mm	210 mm long	200 per 30 cm length	900
				Sub Total	**9000**

TABLE 3.1B: Bought Out Components.

S/N	NAME	FUNCTION	SPECIFI-CATION	QTY	UNIT COST ₦	COST ₦
1	Bolts and nuts	To tighten component to the frame	M6	6	50	300
			M8	6	60	360
			M10	8	70	560
			M12	8	80	640
2	Spur gears	To rotate the chopper knives	Inside diameter = 25 mm	4	300	1200
					Sub Total	**3040**

TABLE 3.1C : Cost of Machining Jobs.

S/N	MATERIAL	TYPE OF JOB	MACHINE USED	TIME SPEED (MIN)	LABOUR COST/HR (₦)	MACHINE COST ₦	TOTAL COST ₦
1	25.4 mm x 25.4 mm x 6 mm angle iron	Cutting	Hacksaw	75	10.00	50.00	126.45
2	Ø 19 mm shaft	Cutting	Power hack saw	4	15.00	25.64	45.75
3	Ø 25.4 mm m.s rod	Size reduction	Students lathe	75	10.00	20.50	65.50
4	Ø 40 mm m.s rod	Cutting	Hacksaw	25	120.00	20.00	350.00
5	Ø 75 mm m.s rod	Cutting	Hacksaw	25	2000.00	20.00	750.20
6	5 mm thick plate	Bending	Pillar	60	100.00	30.00	270.00
						Sub Total	**1607.70**

TABLE 3.1D: Cost of Non Machining Jobs

S/N	JOB	TIME SPENT(HR)	LABOUR COST/HR (₦)	EQUIPMENT COST/HR (₦)	TOTAL COST ₦
1	Marking out	10.00	80.00	4.33	843.00
2	Welding	120.00	160.00	4.00	328.00
3	Machine assembly	2.50	50.00	4.33	135.83
4	Machine dis-assembly for adjustment	2.00	50.00	4.33	108.66
5	Painting	2.00	60.00	4.00	128.00
				Sub Total	**2475.29**

TOTAL COST OF MACHINE PRODUCTION

= **A + B + C + D**

= **9000.00 + 3040 + 1607.70 + 2475.29**

= **N 16122.99**

≅ **N 16,123.**

CHAPTER FOUR

4. EXPERIMENTATION

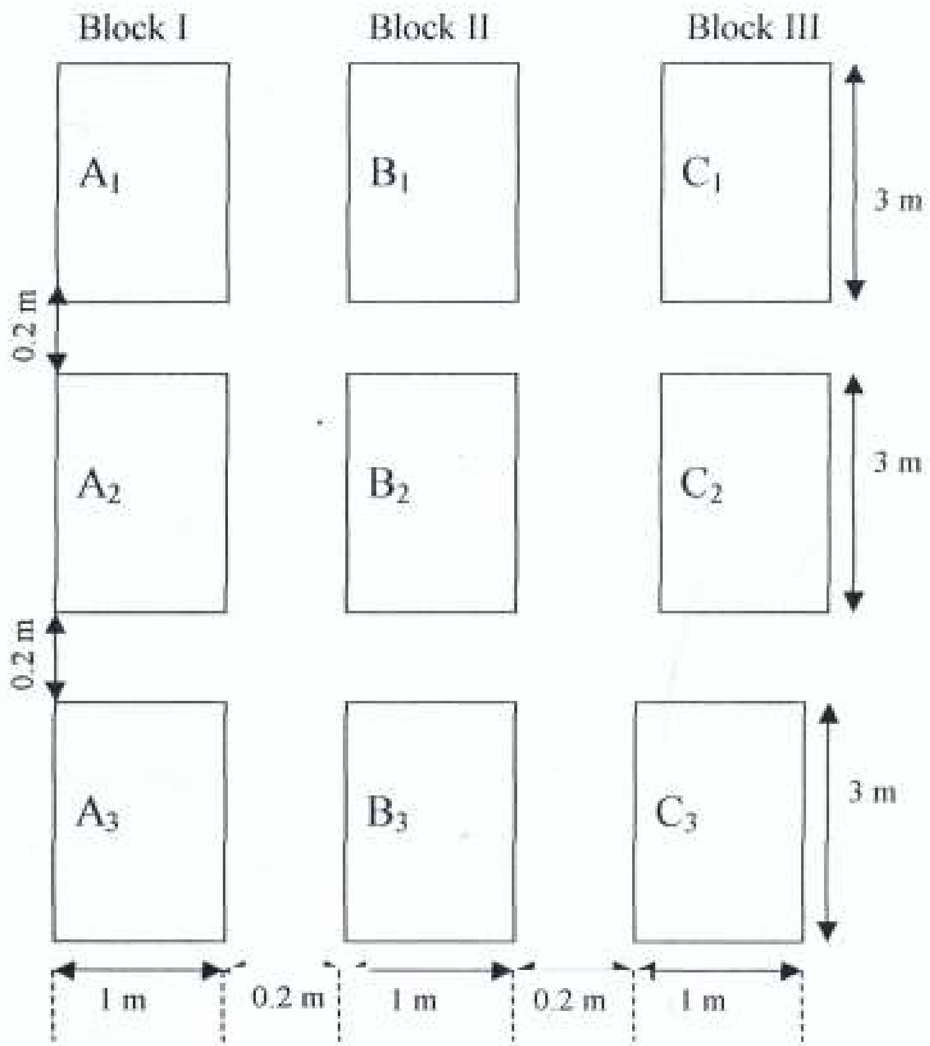
4.1 Preparation of Experimental Plot.

The experimental farm plot was located at the Research Farm of Federal University of Technology, Akure, South Western part of Nigeria. Nigeria is in the tropical region, hence the study area shares the tropical features, such as high temperature, low and unsteady rainfall and irregular relative humidity.

The experimental plot is on longitude $5^0 5^1$ E and latitude 7^0 15^1 N. The topography of the plot was fairly flat. This area was chosen for its suitable soil structure, texture, and water retention capacity and loam fertile soil.

The area of plot was 10 m x 5 m. it was cleared, and the soil was manually loosened with hoe to achieve desired soil tilth. The plot was divided into three block of 1 m x 10 m. Nine beds were made from the plot. The plot were divided into blocks, Block A (A_1, A_2, A_3) Block B (B_1, B_2, B_3), Block C (C_1, C_2, C_3). The view of the experimental plot was shown in Fig. 4.1.

The layout of the experimental plot is as shown below.



Legend:

A Vegetables planted on 9/9/2003
B Vegetables planted on 15/9/2003
C Vegetables planted on 21/9/2003

Block I Moisture content level I
Block II Moisture content level II
Block III Moisture content level III

Fig. 4.1: Experimental Layout

4.2 Planting, Weeding, Thining, and Fertilizer Application.

4.2.1 Planting of Vegetables

Seed of *Amaranthus* were planted by broadcasting method on block A (A_1, A_2, and A_3) on 09/09/2003 on block B (B_1, B_2, and B_3) on 15/09/2003 and on block C (C_1, C_2, and C_3) on 21/09/2003. It germinated on the third day after planting.

4.2.2 Weeding

Weeding started one week after planting of the vegetables. Weeding was done by manually up-rooting the weed. It was repeated after the third and fifth-week after planting.

4.2.3 Thinning

Thinning of the vegetable plot was done second week after planting. Block A (A_1, A_2, and A_3) was thinned to 7 cm spacing, Block B (B_1, B_2, and B_3) was thinned to 5 cm spacing and Block C (C_1, C_2, and C_3) was thinned to 2 cm spacing. The spacing duely affect the vegetable development as can be seen from various photographs taken during harvesting. (Fig. 4.2, 4.3, 4.4 and 4.5)

4.2.4 Fertilizer Application.

In order to improve the rate of the vegetables development, N.P.K fertilizer was broadcast on the various plots at different time.

Fertilizer was applied to block A_1 on the first, second and third weeks after planting, on block A_2 on the first, second, third, and fourth weeks after planting, on block A_3, on the first, second, third, fourth and fifth weeks after planting.

On block B_1, fertilizer was applied on the first and second weeks after planting of the vegetable, on the block B_2 fertilizer was applied on vegetable, first, second and third weeks after planting, and on block B_3, fertilizer was broadcast on first, second, third and fourth weeks after planting.

On block C_1, fertilizer was applied on the first week only, on block C_2, fertilizer was applied on the first and second week after planting of vegetable on block C_3, fertilizer was applied on the first second and third weeks after planting of vegetable. 0.02 kg of N.P.K fertilizer was applied on the aforementioned block (e.g. block A, 0.02 kg of N.P.K fertilizer on first week after planting of vegetable e.t.c.).

The fertilizer applications affected the rate of growth of the vegetables, consequently the stem diameter, which advently influence the mechanical harvesting of the vegetables (Figs. 4.2 to 4.5).

Fig.4.2: Vegetable at the end of 3 weeks after planting

Fig. 4.3: Vegetable at the end of 4 weeks after planting

Fig. 4.4: Vegetable at the end of 5 weeks after planting

Fig. 4.5: Vegetable at the end of 6 weeks after planting

4.3 Measurement of Growth Parameters of *Amaranthus*

The growth parameters of the *amaranthus* that can affect the Performance Efficiency of the machine were measured, such as height and diameter gained by each plant at the end of each week, up to the time of harvesting. The measurement were based on average of 15 plants on each block within the plot. Analysis of variance (ANOVA) was used to analyse the parameters statistically. Details of the result can be found in appendix II. The result of effects of the parameter on the performance of the machine can be found in chapter 6 of this thesis.

4..4. Testing of the Machine

Before evaluating the performance of the machine, (Fig. 3.1) the time at which vegetable was planted was varied, in order to verify the effects of stems and height, of vegetable and consequently the performance of the machine at varying moisture level of the soil of experimental plot.

4.4.1 The performance criteria

The following criteria were used to evaluate the performance of the machine.

i. Field Capacity of the machine. This is the measurement of the area of crop harvested per unit time in ha/h. The performance of an agricultural machine is assessed by the rate at which an operation is accomplished and by the quality of the output.

ii. Field Efficiency – This the ratio of the overall rate of work to the theoretical rate of work.

$$= \frac{\text{Actual Field capacity}}{\text{Theoretical Field capacity}}$$

Its measure in percentage (%)

iii. Quality Performance Efficiency – This is a measure of number of vegetables harvested per number of vegetables plant in the harvested area. This is why prior to operating the machine, the number of vegetable plants in every plot were counted, and also counted after harvesting by machine to determine the number of vegetable plant not harvested (Appendix II) The result can be found on chapter 6 of this thesis.

4.4.2 Test variables

In the operation of the harvester, the following parameters were assumed to have effect on the performance evaluation.

i. Soil moisture content
ii. Soil penetrometer resistance
iii. Age of vegetable
iv. Diameter of vegetable stem
v. Height of vegetable plant

In this work, the variables whose effect on the performance criteria were evaluated are;

1. Soil moisture content of the soil (% wet basis)
2. Age of crop (weeks after planting).

The moisture contents of the soil was varied by adding different measured quantity of water to designated plot before harvesting. The soil samples were taken for moisture content determination by gravimetric method. Table 5.1. To vary the age of crop, vegetable were planted at different periods of one week interval. Cone penetration resistance of the soil were equally measured at the time of harvesting. This is because the ability of the machine to move on varying moisture content on the experimental plot will determine whether the machine will harvest vegetable or not. The data relating to cone penetrometer resistance of the experimental plot can be found in appendix II.

4.4.3 Experimental procedure

The machine was designed to be coupled to the tractor 3-point linkage for harvesting vegetables. However the researcher personally pushed the machine, to able to monitor the harvesting capability of the machine at close range, and the vegetables were satisfactorily harvested in the course. Number of vegetables harvested and number of vegetables not harvested were counted at varying moisture content of the experimental soil.(Table 5.6)

4.5 Performance Test of Machine

During harvesting of the vegetables; it was observed that the soil moisture content has effect on the performance of the machine as affects the smooth movement of the machine. Moreso, the plant population which determined to large extent stem width and height of vegetable plants also affect the performance of the machine (Table 5.4).

Plot C_1 with a congested population of 172 stands, only 62 stands were harvested. This can be attributed to over population, which results competition as well as reduction the stem size of the plant and consequently affect the performance of the machine in harvesting.

CHAPTER FIVE

5. RESULTS AND DISCUSSION.

5.1 RESULTS

All results from the research work were analysed statistically using analysis of variance (ANOVA), including Test of Significance. Details were shown in appendices II – V, while summary of analysed data are presented in following sections. The growth parameters from where the performance characteristic of the machine was determined are shown (Tables 5.2 to 5.6)

5.1.1 Growth parameters of vegetables

Growth parameters of vegetables were recorded during the experiment. It was based on average of 15 vegetables on each block.

Table 5.1 Plants Diameter During the Experiment (In Centimeters)

Date	Plots			$\bar{X}$
20-10-03	A_1	A_2	A_3	For Plot A
	0.60	0.90	1.20	0.90
20-10-03	B_1	B_2	B_3	For Plot B
	0.40	0.60	0.70	0.57
20-10-03	C_1	C_2	C_3	For Plot C
	0.20	0.40	0.3	0.3

Average of diameter of 10 mm of vegetable stem was used in the design calculation

5.1.2 Machine test results

The results of the performances tests of the vegetable harvester in harvesting *amaranthus* grown in the text plot is presented in table 6.2.

TABLE 5.2A: Perfomance Characteristics of Machine

Plot code	Weeks after Planting (wap)	Moisture Contents(% wb)			Field Capacity(ha/h)			Field Efficiency (%)			Quality Performance Efficiency (%)		
		RP_1	RP_2	AV	RP_1	RP_2	AV	RP_1	RP_2	AV	RP_1	RP_2	AV
A_1	6	11.4	12.6	12.0	0.85	0.829	0.82	79.1	81.0	80.1	48	58	53.0
A_2	6	20.5	25.6	23.5	0.760	0.701	0.73	75.2	70.68	72.9	60	61	60.5
A_3	6	30.0	33.0	31.5	0.61	0.610	0.61	61.0	50.12	55.6	40	30	35.0
B_1	5	11.40	13.50	11.24	0.835	0.795	0.82	82.1	79.2	80.6	45	53	49.0
B_2	5	21.50	25.40	23.4	0.754	0.711	0.73	76.5	69.2	72.8	59	56	57.5
B_3	5	31.0	33.50	32.30	0.600	0.590	0.59	58.3	51.1	54.7	59	40	49.5
C_1	4	14.0	15.0	14.50	0.798	0.765	0.78	75.2	71.0	73.1	35	52	43.5
C_2	4	24.5	26.2	25.5	0.700	0.602	0.65	67.1	67.3	67.1	56	40	48.0
C_3	4	30.1	33.10	31.60	0.595	0.513	0.55	60.5	49.1	54.8	38	35	46.5

TABLE 5.2B: Average Perfomance Characteristics of Machine

Plot code	Weeks after Planting (wap)	Moisture Contents (% wb)	Field Capacity(ha/h)	Field Efficiency (%)	Quality Performance Efficiency (%)
		Average	Average	Average	Average
A_1	6	12.0	0.82	80.1	53.0
A_2	6	23.5	0.73	72.9	60.5
A_3	6	31.5	0.61	55.6	35.0
B_1	5	11.24	0.82	80.6	49.0
B_2	5	23.4	0.73	72.8	57.5
B_3	5	32.30	0.59	54.7	49.5
C_1	4	14.50	0.78	73.1	43.5
C_2	4	25.5	0.65	67.1	48.0
C_3	4	31.60	0.55	54.8	46.5

The data (Table 5.1) shows: the Field Capacity (ha/h), Field Efficiency (%) and the Quality Performance Efficiency of the machine at varying age of *amaranthus* and soil moisture level of experimental plot during harvesting. R_1, R_2 and R_3 refer to replicate numbers. The data were used to plot graphs (Figs 5.1, 5.2 and 5.3).

Filed Capacity (ha/h) this is the measurement of the area of crop harvested per unit time in hectare per hour.

$$FC\ (ha/h) = \frac{\underline{\text{Area of harvested plot}}\ (M^2) \times \underline{\text{Time taken}}}{10{,}00m^2}$$

Field Efficiency (%) This is the ratio of overall rate of work to the Theoretical rate of work

$$= \frac{\text{Actual Filed Capacity of a plot}}{\text{Theoretical Filed Capacity}}$$

Quality Performance Efficiency (%) this is a measure of number of vegetable plants harvested per numbers of vegetable plants in the harvested Area

$$= \frac{\text{Number of vegetable plants harvested on plot} \times 100\%}{\text{Total number of vegetable plants on that plot}}$$

TABLE 5.3: Rate of Height Development for Amaranthus on Plots

WEEKS AFTER PLANTING	DATE OF PLANTING	AVERAGE HEIGHT, CM	AVERAGE HEIGHT, CM	AVERAGE HEIGHT, CM	
		PLOT A_1	**PLOT A_2**	**PLOT A_3**	**XA**
1st	15-9-03	5.00	5.20	4.90	5.30
2nd	21-9-03	7.50	7.30	7.00	7.27
3rd	28-9-03	19.00	20.10	22.20	20.43
4th	5-10-03	35.00	37.20	38.00	36.90
5th	12-10-03	41.20	43.00	44.00	42.73
6th	20-10-03	50.00	52.00	63.00	55.00
		PLOT B1	**PLOT B2**	**PLOT B3**	**XB**
1st	21-09-03	3.40	5.30	5.00	4.57
2nd	28-09-03	5.30	7.50	7.60	6.80
3rd	05-10-03	9.90	19.10	18.90	15.97
4th	12-10-03	15.60	28.90	34.40	26.30
5th	20-10-03	25.30	38.30	49.90	37.83
		PLOT C_1	**PLOT C_2**	**PLOT C_3**	**XC**
1st	28-09-03	4.10	5.20	3.90	4.40
2nd	05-10-03	6.30	7.20	8.00	7.17
3rd	12-10-03	12.40	19.00	21.10	17.50
4th	20-10-03	16.90	24.00	26.00	23.30

Average Height of 43 cm was considered, when the vegetable stem will not be tough for the chopper knives.

Table 5.4 Cone Penetrometer Resistance Of Soil Of Experimental Plot During Harvesting.

Cone Penetrometer Resistance, KN/m^2									
Depth in mm	A			B			C		
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3
50	3.80	2.30	1.70	3.60	2.40	1.50	3.50	2.50	1.60
100	16.70	7.60	5.20	16.40	7.50	5.10	15.20	7.10	4.80
150	21.60	15.90	14.60	22.00	18.40	15.00	21.00	10.10	14.00

TABLE 5.5: Number of Vegetable Harvested at a Particular Moisture Content of the Experimental Plot.

PLOTS	HARVESTED STANDS	NOT HARVESTED STANDS	MOISTURE CONTENT (%) OF FARM
A1	58	12	13.40
A2	23	18	25.62
A3	28	15	33.00
B1	30	32	13.45
B2	34	21	25.43
B3	45	10	33.46
C1	62	110	15.20
C2	34	15	25.22
C3	25	10	33.12

5.2 Discussion

Using the data above, to test whether observed variation in the height, of vegetable stem diameter and moisture content of experimental plots had any effect on the harvest-ability of *amaranthus*, data were therefore subjected to statistical analysis using analysis of variance

5.2.1 Field capacity

Field capacity of the machine during harvesting on plot A increases from 0.80 ha/h to 0.83 ha/h at moisture content of 13%. When the moisture content of experimental soil increased further Field Capacity of the machine reduced to 0.6 ha/h of moisture content of 33%(Table 5.1 and Fig 5.1)

Furthermore, on plot C when the moisture content of the experimental soil was 14%, the machine Field Capacity was 0.79ha/h. Further increment in the moisture content of the plot reduced the Field Capacity of the machine (Fig. 5.1and Table 5.1). The reduction in the Field Capacity of the machine as the moisture content increased may be due to in-ability of the machine to move faster on the wet soil. This could also be as result of the stem of the vegetable plants getting tougher due to the attainment of senescent. It could be noticed also that certain moisture level will be reached when the machine will start uprooting the vegetable instead of chopping

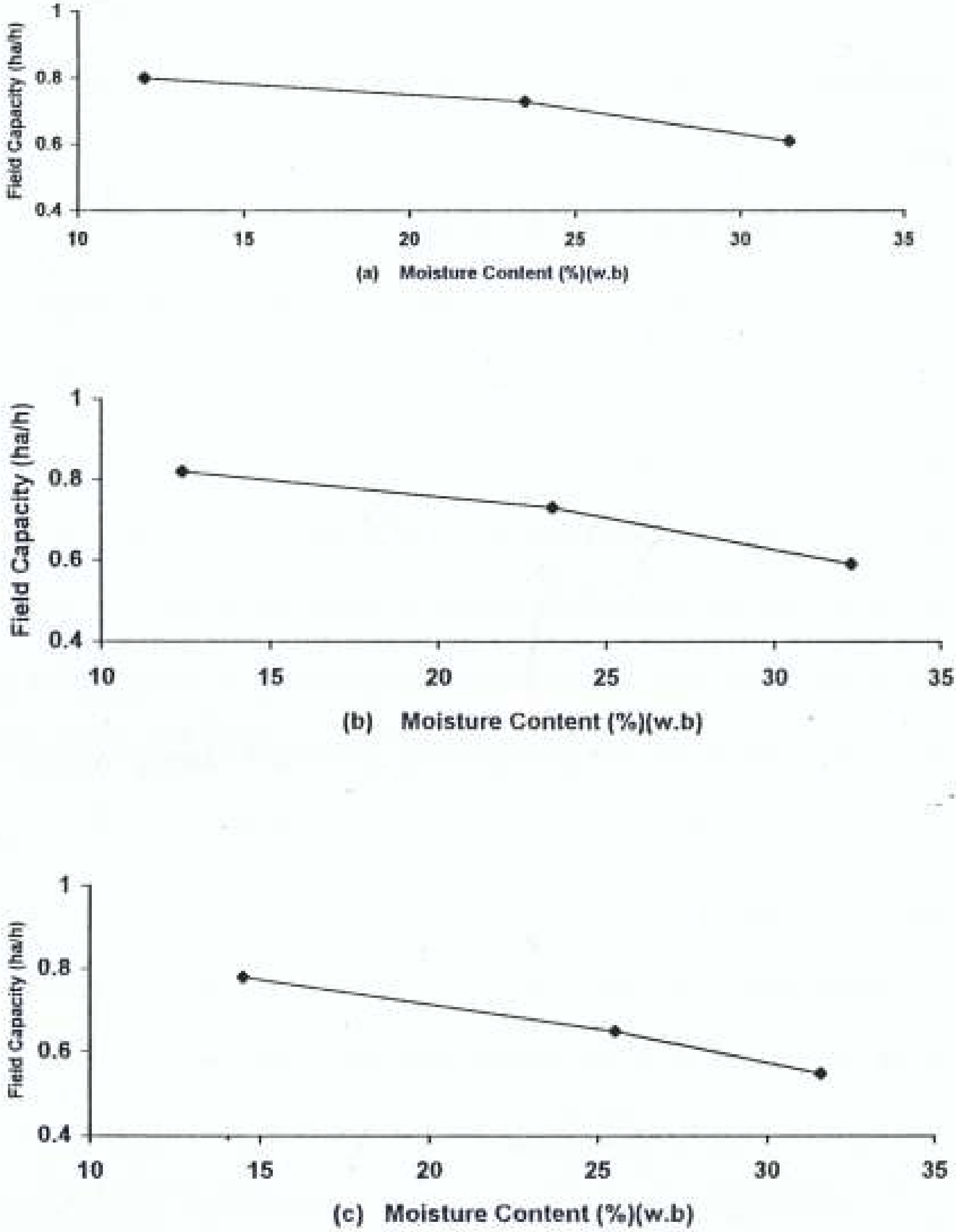


Fig: 5.1 : Effect of Soil Moisture Content on Field Capacity of Machine at (a) 6th Weeks after planting (b) 5th weeks after planting (c) 4th weeks after planting.

5.2.2 Field efficiency

For vegetables harvested at the end of 6th weeks (plot A) one would find out that as the moisture content of the experimental plot increased Field Efficiency of the machine equally increased (Fig 5.2) at 33% moisture level when the Field Efficiency of the machine continue to reduce. This could be due to age of vegetable plants with result in tougher stem of the vegetables.

Field Efficiency of the machine during harvesting on plot B at the end of 5 weeks reduced from 83% to 59 % due to increase in moisture level of the experimental plot. That is the higher the moisture content of the soil, the lower the Field Efficiency. It may also be due to the age of vegetables, and space within vegetable plants. The closer the vegetable the lower the number of vegetable plants that can be harvested (Table 5.1 and Fig 5.2)

Furthermore, at the end of 4 weeks, the number of vegetable plants harvested reduced as the moisture content of the experimental plot increased. It may be due to the vegetable plant stems that are yet to be mature, and stand erect for the chopper knife to chop. It may also be due to over population of the crop in the plot, which leads to reduction in growth and of the plants. It may also be due to the competition for nutrients (Fig 5.2 and Table 5.1)

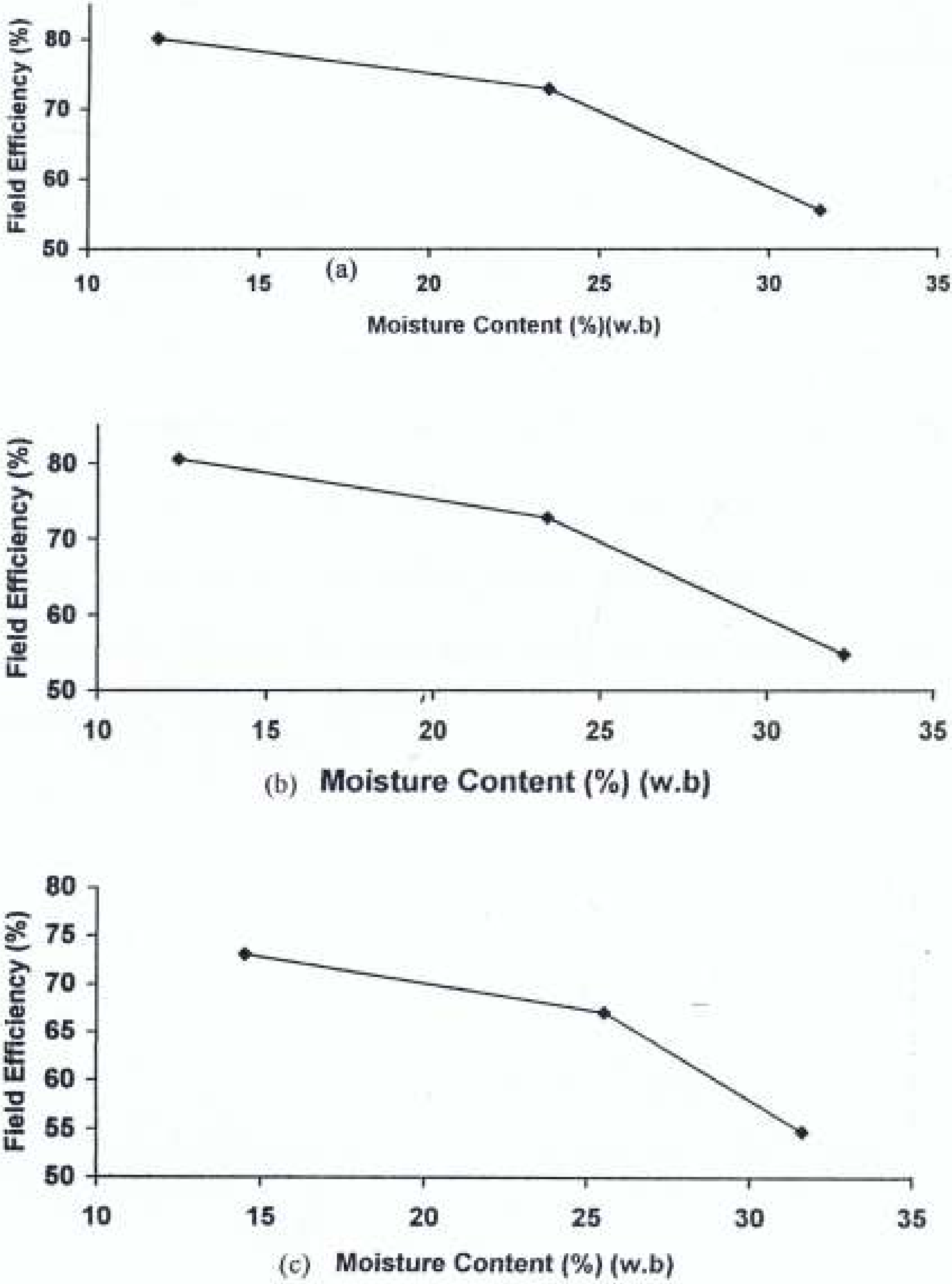
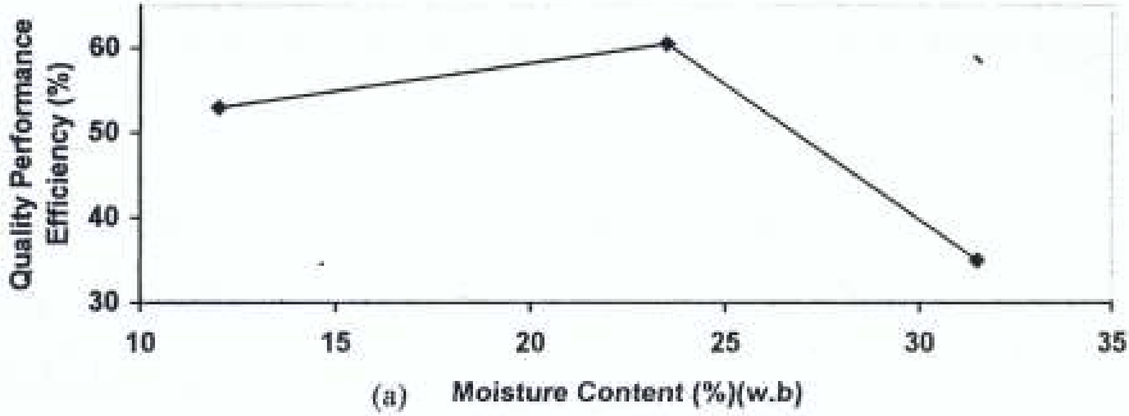


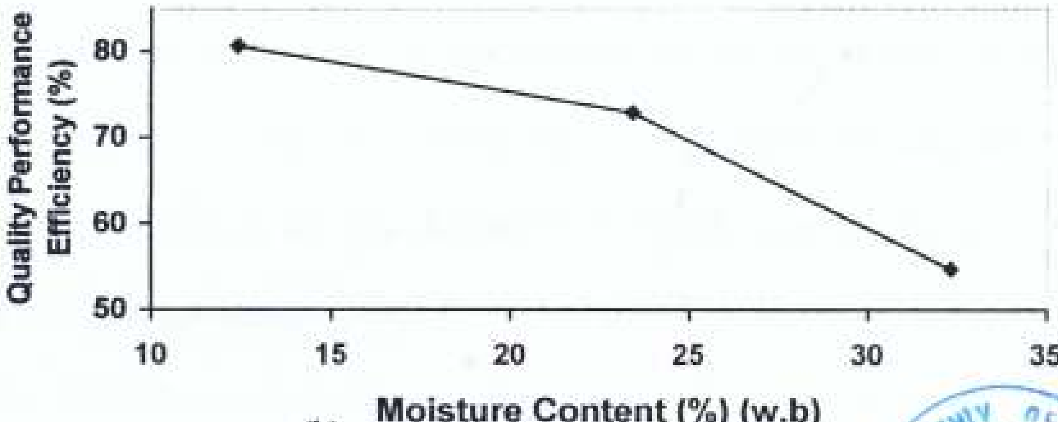
Fig: 5.2 : Effect of Soil Moisture Content on Field Efficiency of Machine at (a) 6th Weeks after planting (b) 5th weeks after planting (c) 4th weeks after planting

5.2.3 Quality performance efficiency

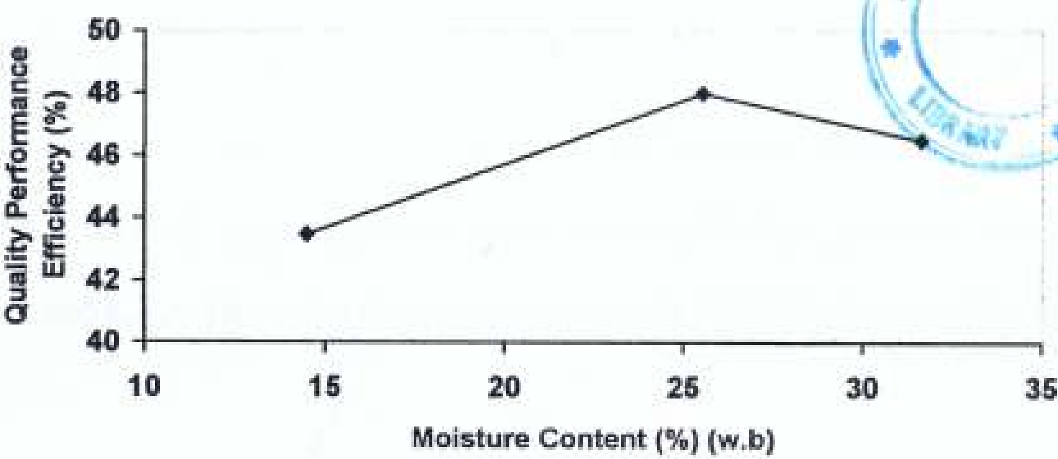
The Quality Performance Efficiency of plots A, B and C increased as the moisture content of the soil in experimental plot increased. One would notice from Table 5.1 and Fig 5.3 that on optimum moisture level was reached the Quality Performance Efficiency of the machine continue to reduce. It may be due to the stem of the plants that vary in size because of difference in time of planting. It may also due to the stem of the plant that was getting tougher with age. It could also be due to the stem of the plants that was thinner when harvested at the end of 4 weeks after planting, or over population of the plants on some plot. Most of the vegetables when the stem were thin were not harvested.



(a)



(b)



(c)

Fig: 5.3: Effect of Soil Moisture Content on Quality Performance Efficiency of Machine at (a) 6th Weeks after planting (b) 5th weeks after planting (c) 4th weeks after planting

5.2.4 Effects of plants diameter on the performance of machine.

Plants diameter affect the performance of the machine. If the diameter of the vegetable is bigger than the space within knives, it will allow the machine to partially cut the stems of the plant or pushed them aside. However, if the stem of the vegetable is smaller than the space within the knives, this will disallow the machine to cut the vegetables.

The stem developed by the vegetable will depend on the age and fertility of the soil. In this study fertilizer was applied to the vegetables to allow it attain adequate diameter at which it will match with the space within the chopper knives. 10 mm diameter will be adequate for this experimental machine; though it can be varied.

5.2.5 Effects of height of vegetables on the performance of the machine.

The height which the vegetables attained at the period of harvesting equally affect the functioning of the machine. If the vegetables are taller than the machine components, it will allow the chopper to push forward the vegetables and will not chop it at the required height, coupled with bigger stem and taller vegetables the machine will push the vegetable only.

5.2.6 Effects of space within vegetables on the performance of the machine

Spaces at which vegetable are planted equally affect the performance of the machine. As shown in Table 5.4, one would find out that wherever you have small number of vegetables on the field, machine performed better coupled with other parameters that affect the performance of the machine like, moisture content, stem diameter of vegetables, height and age. The machine was designed to harvest vegetable at a spacing of 6 cm. This will allow the vegetable to grow well and reach the diameter of stem at which you can harvest it to meet market demand fresh.

5.2.7 Effects of soil resistance of the experimental plot during harvesting.

Cone penetrometer was used to test the soil resistance during harvesting of vegetables (Table 5.5). The table shows the weight that could applied to certain depth in the plot before the soil will shear. This had help determining traffic-ability of the machine at a particular moisture content of the experimental plot. The more the weight, the deeper the depth at which the soil will shear.

Since, different plots had different moisture content the weight of the machine will determine the shearing depth on the soil. If the soil is too wet the machine traffic-ability will be reduced.

CHAPTER SIX

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions.

In this study, a mechanical harvester for fresh leafy vegetables was designed, fabricated and its performance evaluated at different moisture contents of the soil and at varying age of *amaranthus*. The plant height, the plant stem diameter, and space between plants were found to have effect on the performance of the harvester.

This machine enhances easy harvesting of vegetables by peasant farmers, boost agricultural productivity at the local level, and it is affordable to be acquired. The machine is suitable for use on a flat or near flat land, and more importantly on non -water logged area. The efficiency of the machine is greater when used to harvest vegetables 5 weeks after planting at a soil moisture content ranging between 11% and 22% with a plant spacing of 6 cm apart. The maximum Field Capacity, Field Efficiency and Quality Performance Efficiency obtained with the machine were respectively 0.84 ha/h, 82%, and 60%.

6.2 Recommendations

The machine can be used to harvest vegetables on a large scale, and this reduce the drudgery associated with harvesting. However, in order to increase the effectiveness of this vegetable harvester, the following design modifications and improvement are recommended.

(i). There is need to modify the design of chopper knives to accommodate vegetables of different diameters and planting spacing

(ii). The machine power can be more efficiently utilized improving the structure of the four wheels driving the chopper knives.

(iii). In addition, there is need to design a similar machine with greater field capacity since the machine is going to be pulled by tractor during harvesting.

(iv). It is recommended that vegetables should be harvested not later than 5 weeks after planting. Fertilizer can also be applied to hasten rapid development of vegetables so that it can be harvested at the appropriate time before the vegetable stem become too tough for the machine.

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APPENDIX I

3.3.3 Determination of the weight of the Harvester Blade.

The planting distance of vegetable 6 cm x 6 cm. Since the harvester could harvest four rows at a time, a 30 cm cutting was chosen.

Diameter of rod = 0.012 m

Area of the harvester row = Area of the rectangular plate + Area of the three elbow rods. $= (0.3 \times 0.1) + 3\left(\frac{\pi d^2}{4}\right)$

Diameter of rod = 0.012 m

$$= (0.30 \times 0.10) + 3\left[\frac{3.142 \times (0.012)^2}{4}\right]$$

$$= 0.03 + 3\,(0.000113112)$$

$$= 0.03039336\ m^2$$

Area of the harvester row = 0.030 m^2

Volume of the plate = Area of plate x thickness of plate

$$= [(0.30 \times 0.1) \times (0.003)]\ m^3$$

Volume of plate $= 9 \times 10^{-5}\ m^3$

Volume of elbow rod = (Area of rod x length of rod) x 3

$$= 3\left(\frac{3.142 \times (0.012)^2}{4}\right)$$

$$= 0.000067867\ m^3$$

Volume of elbow rod = $6.79 \times 10^{-5}\ m^3$

Total volume of one harvester row = $(9 \times 10^{-5} + 6.79 \times 10^{-5})\ m^3$

$= 1.58 \times 10^{-4}\ m^3$

For eight harvester row = $8(0.000157867)\ m^3$

$= 1.26 \times 10^{-3}\ m^3$

Metal was the material selected to ensure maximum strength for the harvesting exercise.

Density of metal is 7860 kg/m^3

Mass of metal = Density x Volume

$= 7860\ kg/m^3 \times 0.00126$

$= 9.9036$ kg.

Weight of one harvesting row = mass x acceleration due to gravity.

$= 9.9036 \times 9.81$

$= 97.154$ N

3.3.4 Determination of the weight of the gears.

The gears are assumed to be circular solid

Diameter of the gear = 5 cm = 0.05 m

Thickness of the gear = 2.5 cm = 0.025 m

$$\text{Volume of the gear} = \frac{\pi D^2}{4} \times \text{thickness}$$

$$= 3.142 \frac{(0.05)^2}{4} \times 0.025 \text{ m}^3$$

$$= 4.91 \times 10^{-5} \text{ m}^3$$

Volume of four gears $= 4 \times 4.91 \times 10^{-5}$

$$= 1.96 \times 10^{-4} \text{ m}^3$$

Weight of gears $=$ volume x density x 9.81

$$= 1.96 \times 10^{-4} \times 7860 \times 9.81$$

$= 15.11$ N $= 7.56$ N weight of two gears.

3.3.5 Determination of weight of anchor for lower link.

The anchor is circular solid disc

Diameter of the disc = 10 cm = 0.01 m

Thickness of the disc = 2 cm = 0.02 m

Volume of the disc $= \frac{\pi D^2}{4}$ x thickness

$$= \pi \frac{(0.01)^2}{4} \times 0.02$$

$$= 0.000000157 \text{ m}^3$$

$$= 1.57 \times 10^{-7} \text{ m}^3$$

Weight of the anchor = volume x density x 9.81

$$= 1.57 \times 10^{-7} \times 7860 \times 9.81$$

$$= 1.21 \times 10^{-2} \text{ N}$$

3.3.6 Determination of the number of chopper rows on the harvester shaft.

The time (t) for the harvester to cover distance $\frac{\pi d}{n_c}$ should be just a little lower than the time (t) for the machine to cover distance 'S'

The time (t) for the harvester to cover distance 'S'. = s/v

$$t = s/v \quad \ldots\ldots\ldots\ldots\ldots 1$$

:- The time (t) for the harvester to cover distance $\frac{\pi d}{n_c} = \frac{\pi d/n_s}{\pi d n_r}$

Where n_r = rotational speed of the harvester

$$= \frac{\pi d}{n_c} \times \frac{1}{\pi d n_r}$$

$$t = \frac{1}{n_c n_r} \quad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

Equating (1) and (2)

$$s/v = \frac{1}{n_c n_r}$$

$$s n_c n_r = v$$

But $\frac{1}{n_c n_r} < \frac{s}{v}$

$$s n_c n_r < v$$

$$n_c \leq \frac{v}{s n_r}$$

Where s = spacing (m)

n_c = number of rows on the harvester rotor (rps)

d = diameter of harvester (m)

v = linear speed of the harvester (m/s)

t = time (second).

The spacing of vegetable ≤ 6 cm ≤ 0.06 m

The maximum velocity of the harvester blade = v

V = 2.5 km/hr or 0.69 m/s was selected

$$V = \left[\frac{2.5 \times 1000}{60 \times 60}\right] = 0.69 \text{ m/s}$$

But $n_c \leq v/sn_r$

If $n_r = 100$ rpm or 1.67 rps

$$n_c \leq \frac{0.69 \text{ m/s}}{0.06 \times 1.67}$$

$nc \leq 6.886$

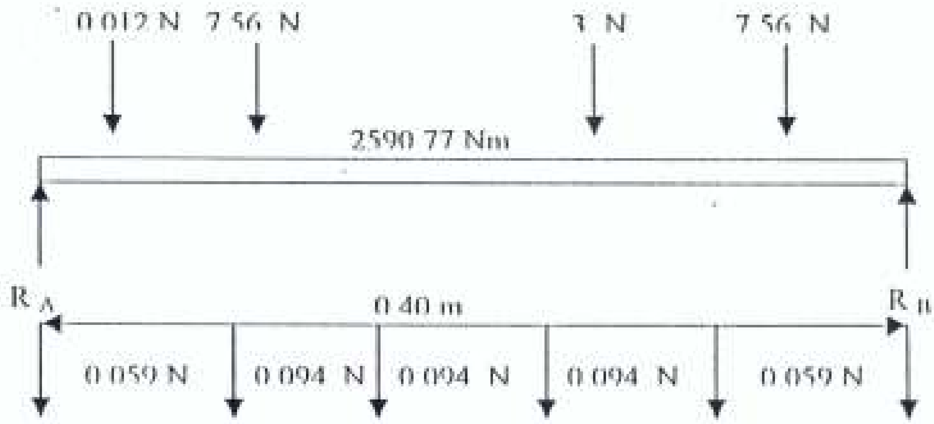
≈ 7 rows. Eight rows was selected

The force due to one row on the harvester element is (97.154 x 8) N = 777.23N

The force is uniformly distributed over 30 cm length of equipment shaft. $= \frac{777.23 \text{ N}}{0.30}$

= 2590.77 Nm

3.3.7 DESIGN OF SHAFT



$\Sigma F\downarrow = \Sigma F\uparrow$

$R_A + R_B = (0.012 + 7.56 + 3.0 + 777.23 + 7.56)$ N

$\mathbf{R_A + R_B = 795.36\ N}$

Taking moment about A.

$= -0.012 \times 0.059 - 7.56 \times 0.153 - 777.23 \times 0.247 - 3 \times 0.341 -$

$7.56 \times 0.36 + 0.4\ R_B = 0$

$- 0.000708 - 1.15668 - 191.9758 - 1.02 - 2.7216 + 0.4\ R_B = 0$

$0.4\ R_B = 196.874788$

$R_B = 492.18697$ N

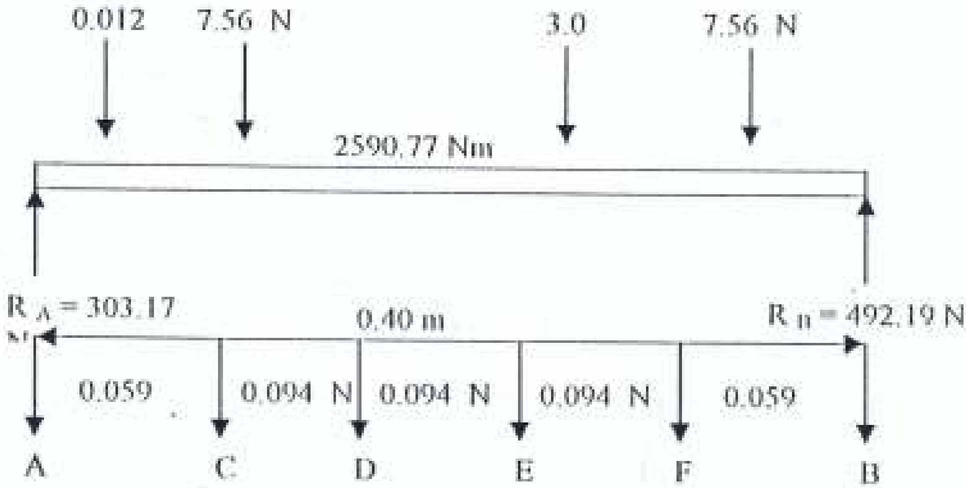
Since $R_A + R_B = 795.36$

$R_A + 492.18697 = 795.36$

$R_A = 795.36 - 492.18697$

$RA \approx 303.17$ N

Vertical loading.



Vertical Bending Moment (V_{BM})

At A $M_{BV} = 0$

At C where x = 0.059

$= 303.17 \times 0.059$

= 17.89 Nm

At D when x = 0.153 m

$M_{BV} = 303.17 \times 0.153 - 0.012 \times 0.094$

= 46.38 Nm

At E when x = 0.247 m

M_{BV} = 303.17 x 0.247 – (0.012 x 0.188) – (7.56 x 0.094) – (2590.77 x 0.094) x (0.047 + 0.059)

= 74.88299 – 0.002256 – 0.71064 – 25.8144

≈ 48.36 Nm

At F when x = 0.341 m

303.17 x 0.341 – (0.012 x 0.282) – (7.56 x 0.188) – (2590.77 x 0.188) x (0.094 + 0.059) – (3.0 x 0.094)

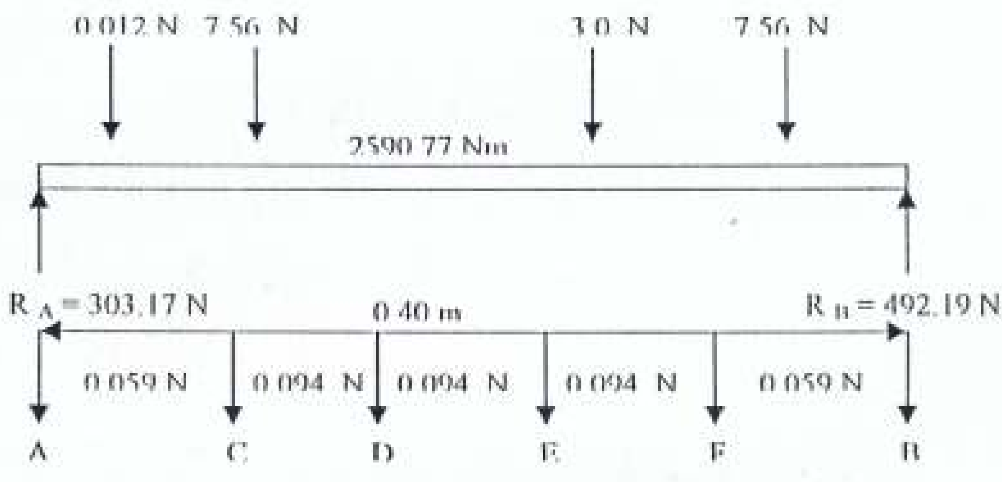
= 103.38097 – 0.003384 – 1.42128 – 74.52091 – 0.282

≈ 7.16 Nm

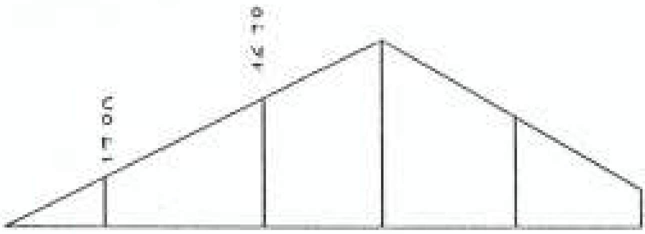
At B when x = 0.40 m

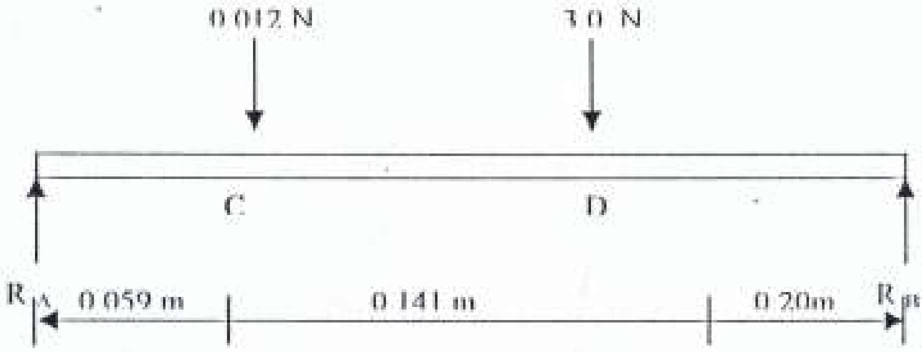
MBV = 303.17 x 0.4 – (0.012 x 0.341) – (7.56 x 0.247) – (777.23 x 0.188) – (3 x 0.153) – (7.56 x 0.059)

= 22.074788 Nm.



HORIZONTAL LOADING





EF = EF

$R_A \downarrow + R_B \uparrow = (0.012 + 3)$ N

$= 3.012$ N

$R_A + R_B = 3.012$ N

Taking moment about A

$-(0.012 \times 0.059) - (3 \times 0.20) + (0.4 R_B) = 0$

$-0.000708 - 0.6 + 0.4 R_B = 0$

$0.4 R_B = 0.600708$

$R_B = 1.501$ N

Substitute for R_B

$R_A + 1.501 = 3.012$ N

$R_A = (3.012 - 1.501)$ N

$= 1.51$ N

H_{BM} at A = 0

M_{BH} at B = $(1.51 \times 0.4) - (0.012 \times 0.341) - (3 \times 0.020)$

$= 0.604 - 0.004092 - 0.6$

≈ 0 Nm

M_{BH} at C $= 1.51 \times 0.059$

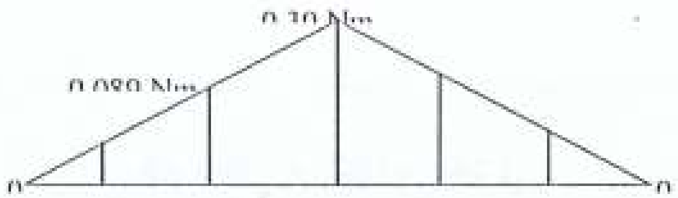
$= 0.08909$ Nm

≈ 0.089 Nm

M_{BH} at D $= (1.51 \times 0.2) - (0.012 \times 0.141)$

$= 0.302 - 0.001692$

$= 0.300$ Nm



$d^3 = 0.000000147\ (5262.0516 + 25437.0601)^{-2}$

$d^3 = 0.000000147\ (30699.1117)^2$

$d^3 = 1.47 \times 10\text{-}7\ (175.2116198)$

$d^3 = 0.000025756$

$d^3 = 0.00295$ m

$d^3 \approx 0.03$ m

Thus 30 mm standard diameter shaft was selected.

3.3.8 *Determination of the weight of the harvester shaft.*

The material selected for the shaft is metal for the purpose of strength required in the harvesting.

Length of the shaft = 40 cm = 0.4 m = L

Diameter of the shaft = 30 mm = 0.030 m = D

$$\text{Volume} = \text{Area x length of the shaft}$$

$$= \frac{\pi D^2}{4} \times L$$

$$= \pi \frac{(0.030)^2}{4} \times 0.40$$

$$= 0.00028278 \text{ m}^3$$

$$= 2.83 \times 10^{-4} \text{ m}^3$$

Weight of shaft = volume x density x acceleration due to gravity.

$$= 2.83 \times 10^{-4} \times 7860 \times 9.81 \text{ N}$$

$$= 21.80 \text{ N}$$

3.3.9 *Determination of the power required to drive the harvester.*

The forces acting on the shaft are:

F_1 = Resistance of the crop = 3 N

F_2 = Weight of the (8) eight harvester blade = 2590.77 N

F_3 = Weight of the driven and driving gears = 15.11 N

F_4 = Weight of the anchor for lower links = 0.012 N

F_5 = Weight of shaft = 21.80

Total weight = (3 + 2590.77 + 15.11 + 0.012 + 21.80) N

F = 2630.692 N.

At a shaft speed of 100 rpm or 1.67 rps

$$\text{Power (p)} = \frac{\text{Forces x Distance}}{\text{Time}}$$

$$= \frac{2630.69 \times 0.69}{1}$$

$$= 1815.17748 \text{ W}$$

$$= 1.815 \text{ Kw}$$

Kw = 1.34 hp (hp = horse power)

1 hp = 0.746 Kw

$$\frac{\textbf{1 Kw}}{1.815\text{Kw}} = \frac{\textbf{1.34 hp}}{x}$$

x = 1.815 x 1.34

x = 2.4321 hp

Power required to drive the harvester blade ≈ 2.43 hp

APPENDIX II

Considering Table 6.1

Considering table 6.1:

1. Total moisture content for plot A = 133.12

Average =133.12- 6

= 22.19%

Total moisture content for plot B = 136 .24

Average =136.24 –6

= 22.71 %

Total moisture content for plot C = 132.96

Average = 132.96 –6

= 22.16%

Average moisture content for plot $\frac{A+B+C}{3}$

$= \frac{22.19 + 22.71 + 22.16}{3}$

= 22.35%

2. Total field capacity for Plot A 0.430.58

Average = 0.430.58 –6

= 0.71.76 ha/h

Total Filed Capacity for plot B = 0.429

Average = 0.429 –6

= 0.71.50 ha/h

Total Filed Capacity for plots C = 0.406 .3

Average = 0.429-6

= 0.71 .50 ha/h

Total Filed Capacity for plot $\frac{A+B+C}{3}$

= 0.7176 +0.7150 +0.6772 =0.732 ha/h

3. Total Filed Efficiency for Plot A = 417.13

Average = 417.1-6

= 69.52 %

Total Field Efficiency for Plot B = 416.40

Average = 416.40 –6

= 69.40 %

Total Field Efficiency for Plot C= 390.21

Average =390.221-6

=65.04%

Average Filed Efficiency for Plot $\frac{A+B+C}{3}$

$= \frac{69.52+69.40+65.04}{3}$

= 67.99%

Total Quality Performance Efficiency for plot A = 297

Average 297-6

Total Quality Performance Efficiency for plot B = 302

Average = 302-6

= 49.50%

Total Quality Performance Efficiency for Plot B = 302

Average = 302-6

50.33%

Total Quality Performance Efficiency for Plot $\frac{A+B+C}{3}$

$= \frac{49.50+50.33+42.67}{3}$

= 47.50%

Calculation of Filed Efficiency

$A1 = \frac{55}{70} \times 100 = 79.10\%$

$A1 = \frac{58}{70} \times 100 = 81\%$

$A2 = \frac{30}{41} \times 100 = 75.20\%$

$A2\ \frac{28}{41} \times 100 = 70.68\%$

$A3 = \frac{26}{43} \times 100 = 61\%$

$A3 = \frac{22}{43} \times 100 = 50.12\ \%$

$B1 = \frac{51}{62} \times 100 = 82.10\%$

$$B2 = \frac{42}{55} \times 100 = 76.50\ \%$$

$$B2\ \frac{38}{55} \times 100 = 59.20\%$$

$$B2 = \frac{32}{55} \times 100 = 69.20\%$$

$$B3 = \frac{28}{55} \times 100 = 51.10\ \%$$

$$C1 = \frac{35}{49} \times 100 = 75.20\%$$

$$C1 = \frac{35}{49} \times 100 = 71.00\%$$

$$C2\ \frac{31}{46} \times 100 = 67.10\%$$

$$C2\ \frac{29}{46} \times 100 = 64.30\ \%$$

$$C3\ \frac{21}{35} \times 100 = 60.51\ \%$$

$$C3\ \frac{17}{35} \times 100 = 49\ .10\%$$

Calculation of Quality Performance Efficiency

$$A1 = \frac{34}{70} \times 100 = 48\%$$

$$A1 = \frac{41}{70} \times 100 = 58\ \%$$

$A2\ \frac{25}{41} \times 100 = 61\%$

$A2\ \frac{25}{41} \times 100 = 60\%$

$A3 = \frac{17}{43} \times 100 = 40\%$

$A3 = \frac{13}{43} \times 100 = 30\%$

$B1 = \frac{27}{62} \times 100 = 45\%$

$B1 = \frac{32}{62} \times 100 = 53\%$

$B2 = \frac{32}{55} \times 100 = 59\%$

$B2 = \frac{30}{55} \times 100 = 56\%$

$B3 = \frac{22}{55} \times 100 = 40\%$

$C1 = \frac{17}{49} \times 100 = 35\%$

$C1 = \frac{25}{49} \times 100 = 52\%$

$C2 = \frac{25}{46} \times 100 = 56\%$

$C2 = \frac{18}{46} \times 100 = 40\ \%$

$$C3 = \frac{13}{35} \times 100 = 38\%$$

$$C3 = \frac{12}{35} \times 100 = 35\%$$

Calculation of Field Capacity

$$\text{Block A1} = \frac{134 \times 60}{10{,}000} = 0.805 \text{ ha/h}$$

$$A1 = \frac{138}{10{,}000} \times 60 = 0.8286 \text{ ha/h}$$

$$A2 = \frac{126}{10{,}000} \times 60 = 0.76 \text{ ha/h}$$

$$A2 = \frac{116}{10{,}000} \times 60 = 0.701 \text{ ha/h}$$

$$A3 = \frac{101}{10{,}000} \times 60 = 0.61 \text{ ha/h}$$

$$A3 = \frac{100}{10{,}000} \times 60 = 0.6012 \text{ ha/h}$$

$$B1 = \frac{139}{10{,}000} \times 60 = 0.835 \text{ ha/h}$$

$$B2 = \frac{125}{10{,}000} \times 60 = 0.754 \text{ ha/h}$$

$$B2 = \frac{118}{10{,}000} \times 60 = 0.711 \text{ ha/h}$$

$$B3 = \frac{100}{10{,}000} \times 60 = 0.60 \text{ ha/h}$$

$B3 = \frac{98}{10,000} \times 60 = 0.59$ ha/h

$C1 = \frac{133}{10,000} \times 60 = 0.798$ ha/h

$C1 = \frac{127}{10,000} \times 60 = 0.765$ ha/h

$C2 = \frac{116}{10,000} \times 60 = 0.70$ ha/h

$C2 = \frac{100}{10,000} \times 60 = 0.602$ ha/h

$C3 = \frac{99}{10,000} \times 60 = 0.595$ ha/h

$C3 = \frac{85}{10,000} \times 60 = 0.513$ ha/h

1. Total Moisture Content for Plot A

Calculation of Field Capacity.

A_1 ..... $\frac{58}{58+12} \times 100 = 82.86\%$

A_2..... $\frac{23 \times 100}{23+18.} = 56.10\%$

A_3..... $\frac{28 \times 100}{28+15} = 65.12\%$

B_1---- $\frac{30 \times 100}{30+32} + 48.39\%$

B_2---- $\frac{34 \times 100}{34+21} = 61.82\%$

B_3---$\frac{45 \times 100}{45 + 10} = 81.82\%$

C_1---- $\frac{62 \times 100}{34 + 15} = 36.05\%$.

C_2----$\frac{34 \times 100}{34 + 15} = 69.39\%$

C_3----$\frac{25 \times 100}{25 + 10} = 71.43\%$

Calculation of Functional Efficiency

A_1----- $\frac{869}{869 + 230} \times 100 = 79.07\%$

A_2----- $\frac{892}{892 + 370} \times 100 = 70.68\%$

A_3----- $\frac{2140}{2140 + 920} \times 100 = 69.93\%$

B_1----- $\frac{482}{482 + 200} \times 100 = 70.88\%$

B_2----- $\frac{872}{872 + 210} \times 100 = 80.59\%$

B_3----- $\frac{1592}{1592 + 500} \times 100 = 76.10\%$

C_1----- $\frac{502}{502 + 310} \times 100 = 61.82\%$

$$C_2\text{-----} \frac{748}{748 + 190} \times 100 = 79.74\%$$

$$C_3\text{-----} \frac{760}{760 + 230} \times 100 = 76.77\%$$

APPENDIX III

*TABLE 4.1.5*ANOVA TABLE FOR PLOT MOISTURE CONTENT DURING HARVESTING.

S/N	PLOT			Treatment
	A	B	C	
1	13.40	13.45	15.02	41.87
2	25.62	25.43	26.22	77.27
3	33.00	33.46	33.12	99.58
Block total	72.34	72.34	74.36	218.72

The moisture content of the experimental plot was varied during harvesting. The anova table above shows the variation in the moisture content. It would subjected to statistical analysis using analysis of variance to determine whether there is significant difference in the plot moisture content. This will therefore be used to test whether the observed variation in moisture affect the harvest-ability/efficiency of the machine. Randomize block design was used.

Step I: Calculate the error-term C (correction factor).

$$C = \frac{(\Sigma X)^2}{N} = \frac{(13.40 + 13.45 + \ldots\ldots + 33.12)^2}{9}$$

$$= \frac{(218.72)^2}{9}$$

$$C = \underline{5315.38}$$

Step II: Calculate total sum of squares

$$SS_t = \Sigma X^2 - C$$

$$SS_t = 13.40^2 + 13.45^2 + \ldots\ldots + 33.12^2 - 5315.38$$

$$=5882.12 - 5315.38$$

$$SS_t = 566.74.$$

Step III: Calculate treatment sum of square

$$SS_m = \frac{\Sigma T_A^2}{N_A} + \frac{\Sigma T_B^2}{N_B} + \frac{\Sigma T_C^2}{N_C} - C$$

$$= \frac{(72.02)^2}{3} + \frac{(72.34)^2}{3} + \frac{(74.36)^2}{3} - C$$

$$= 1728.96 + 1744.36 + 1843.14 - 5315.38$$

$$SS_m = 108$$

Step IV: Calculate error sum of square.

$$\textbf{Error SS} = \Sigma T_A^2 - \Sigma\frac{(T_A)^2}{N_A} + \Sigma T_B^2 - \Sigma\frac{(T_B)^2}{N_B} + \Sigma T_C^2 - \Sigma\frac{(T_C)^2}{N_C}$$

$$= 1924.94 - 17.28.96 + 1947.16 - 1744.36 + 2010.02 - 1843.14$$

Error SS = 565.66

Step V: Calculate the mean square (MS)

$$\text{Total MS} = \frac{\text{Total SS}}{\text{Total df}(N - 1)}$$

$$= \frac{566.74}{8}$$

Total MS = 70.71

Step VI: Calculate Treatment MS

$$\text{Treatment MS} = \frac{\text{Treatment SS}}{\text{Treatment df } (t - 1)}$$

$$= \frac{1.08}{3 - 1}$$

= 0.54.

Step VII Calculate Error MS

$$\text{Error MS} = \frac{\text{Error SS}}{\text{Error df } (n - t)}$$

$$= \frac{565.66}{9 - 2}$$

Error MS = 80.81

Step VIII: Calculate F ratio

$$\text{F ratio} = \frac{\text{Treatment MS}}{\text{Error MS}}$$

$$= \frac{0.54}{80.81}$$

F ratio = 0.0067.

TABLE 4.16

Source	df	SS	MS	F
Block	2			
Treatment	2	1.08	0.54	
Error		565.66	8.81	0.0067
Total	1	566.74	70.71	

Calculated F is 0.0067.

Theoretical F, 0.05, 2, 7 df = 4.74

The calculated F is less than theoretical F, therefore we accept the null hypothesis that there is no significant difference in the moisture content of the plot during harvesting of the *amaranthus* to impede the functionality of the experimental machine..

Table 4.4 ANOVA TABLE FOR PLANTS HEIGHT

WEEK	PLOT		
	A	B	C
1st	5.03	4.57	4.40
2nd	7.27	6.80	7.17
3rd	20.43	15.97	17.50
4th	36.90	26.30	22.30
5th	42.73	37.83	
6th	55.00		
Total	167.36	91.47	51.37
Treatment X	27.89	18.29	12.84

Looking at the data above, it will be used to test whether observed variation in the height of *amaranthus* would affect the harvestibility /

efficiency of the machine. It would therefore be subjected to statistical analysis using analysis of variance to determine whether there is significant difference in the height of the plants. Complete randomizes block design was used.

Step I: Calculate the error term C (Correction factor).

$$C = \frac{(\Sigma X)^2}{N}$$

$$= \frac{(5.03 + 4.57 + 4.40 + ... + 55.0)^2}{15}$$

$$= \frac{(310.20)^2}{15}$$

$$C = \underline{6414.84}$$

Step II: Calculate total sum of squares

$$SS_t = \Sigma X^2 - C$$

$$\mathbf{\Sigma X^2 = 5.03^2 + 4.57^2 + ... + 55^2}$$

$$= 10027.28$$

$$SS_t = 10027.28 - 6414.94$$

$$SS_t = 3612.34$$

Step III: Calculate treatment sum of square

$$SS_m = \frac{\Sigma T_A{}^2}{N_A} + \frac{\Sigma T_A{}^2}{N_B} + \frac{\Sigma T_C{}^2}{N_C} - C$$

$$= \frac{167.362}{6} + \frac{91.472}{5} + \frac{51.372}{4} - 6414.94$$

$$= 4668.23 + 1673.35 + 659.72 - 6414.94$$

$$= 7001.30 - 6414.94$$

$SS_m = 586.36$

Step IV: Calculate error sum of square

$$\text{Error SS} = \text{Error SS} = \Sigma T_A^2 - \Sigma\frac{(T_A)^2}{N_A} + \Sigma T_B^2 - \Sigma\frac{(T_B)^2}{N_B} + \Sigma T_C^2 - \Sigma\frac{(T_C)^2}{N_C}$$

$\Sigma T_A^2 = 6708.00$

$\Sigma T_B^2 = 2444.96$

$\Sigma T_C^2 = 874.31$

Error SS $= 6708 - 4668.23 + 2444.96 - 1673.35 + 874.31 - 659.72$

$= 9.77 + 771.61 + 214.59$

Error SS $= 995.97$

Step V: Calculate mean square (MS)

$$\text{Total MS} = \frac{\text{Total SS}}{\text{Total df } (N-1)}$$

$$= \frac{3612.34}{15 - 1}$$

Total MS $= 258.02$

Step VI: Calculate Error MS

Error MS = $\frac{\text{Error SS}}{\text{Error df } (N - t)}$

df = degree of freedom

Error MS = $\frac{955.97}{14 - 2}$
= 83.00

Step VII: Calculate F ratio

= $\frac{\text{Treatment MS}}{\text{Error MS.}}$

F ratio = $\frac{293.18}{83.00}$

= 3.53

TABLE 4.5

Source	df	SS	MS	F
Block	2			
Treatment	2	586.36	293.18	
Error	12	995.97	83.00	3.53
Total	16	3612.34	258.02	

Calculated F is 3.53

Theoretical F, 0.05, 2, 12, df = 3.89.

Calculated F is less than theoretical F, there we accept the null hypothesis, that there is no significant difference in the height of the vegetables to make harvesting impossible for the experimental machine.

TABLE 4.9 ANOVA TABLE FOR PLANTS STEM DIAMETER

PLOTS

S/N	A	B	C	**Treatment total**
1	0.60	0.40	0.20	1.20
2	0.90	0.60	0.40	1.90
3	1.20	0.70	0.30	2.20
Block total	2.70	1.70	0.90	5.30

The above *amaranthus* stem diameter was subjected to statistical analysis of variance to determine whether there is significant difference in the plant stem diameter that can disrupt the harvest-ability of the experimental machine. Randomize block design was used.

Step I: Calculate the error –term C (correction factor)

$$C = \frac{(\Sigma X)^2}{N} = \frac{(0.60 + 0.40 + 0.20 + \ldots + 0.30)^2}{9}$$

$$= \frac{(5.3)^2}{9}$$

C = 3.12

Step II: Calculate total sum of square (SS)

$$\text{Total SS} = \Sigma X^2 - C$$

$$= (0.6)^2 + 0.4^2 + 0.2^2 + \ldots\ldots + 0.3^2 - C$$

$$= 3.91 - 3.12$$

$$= 0.79$$

Step III: Calculate block sum of square (SS)

$$\text{Blocks SS} = \frac{\Sigma B^2}{N} - C$$

N is the number of bloc

$$= \frac{2.7^2 + 1.7^2 + 0.9^2 - 3.12}{3}$$

$$= 3.66 - 3.12$$

$$= 0.54.$$

Step IV: Calculate treatment sum of square (SS_{m})

$$\text{Treatment SS} = \frac{\Sigma T^2}{N} - C$$

$$= \frac{1.2^2 + 1.9^2 + 2.2^2 - 3.12}{3}$$

$$= 3.30 - 3.12$$

$$= 0.18$$

Step V: Calculate Error SS

Error SS = Total SS – Block SS – Treatment.

$$= 0.79 - 0.54 - 0.18$$

$$= 0.07$$

Step VI: Calculate the mean square (MS)

$$\text{Total MS} = \frac{\text{Total SS}}{\text{Total df}} = \frac{3.76}{9-1}$$

$= 0.47$

Step VII Calculate Block MS

$$\text{Block MS} = \frac{\text{Block SS}}{\text{Block df}} = \frac{0.54}{3-1} = 0.27$$

Step VIII: Calculate the treatment MS.

$$\textbf{Treatment MS.} = \frac{\text{Treatment SS}}{\text{Treatment df}}$$

$$= \frac{0.18}{3-1}$$

$= 0.09$

Step IX: Calculate Error MS

$$\text{Error MS} = \frac{\text{Error SS}}{\text{Treatment df} - \text{block } \mathbf{df}}$$

$$= \frac{0.07}{2 \times 2}$$

$= 0.0175$

TABLE 4.10

Source	**df**	**SS**	**F**	
Block	2	0.54	0.27	
Treatment	2	0.18	0.09	4.50
Error	4	0.07	0.02	
Total	8	0.79	0.47	

Calculated F is 4.50

Theoretical F, 0.05, 2, 4 df = 6.94
Since the calculated F is less than the theoretical F, we, therefore accept the null hypothesis that there is no significant difference in *amaranthus* stem diameter to make the harvest-ability of the experimental machine possible or to reduce the efficiency of the machine.