DESIGN, DEVELOPMENT AND TESTING OF A TRANSPLANTING MECHANISM FOR CONVENTIONAL PADDY SEEDLINGS

By

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Thesis submitted to the Punjab Agricultural University
in partial fulfilment of the requirements for the degree of

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in
Farm Power and Machinery

Department of Farm Power and Machinery
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LUDHIANA

1979

C E R T I F I C A T E - I

This is to certify that this thesis entitled "Design, Development and Testing of a Transplanting Mechanism for Conventional Paddy Seedlings" submitted for the degree of M. Tech. in the subject of Farm Power and Machinery of the Punjab Agricultural University, is a bonafide research work carried out by Cheeram Parambil Muhammad under my supervision and no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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C E R T I F I C A T E -II

This is to certify that the thesis entitled "Design, Development and Testing of a Transplanting Mechanism for Conventional Paddy Seedlings" submitted by Cheeram Parambil Muhammad to the Punjab Agricultural University in partial fulfilment of the requirements for the degree of M.Tech. in the subject of Farm Power and Machinery has been approved by Student's Advisory Committee after an oral examination on the same in collaboration with an External Examiner.

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ABSTRACT

A mechanism to transplant washed-root seedlings upto 30 cm length was developed and tested. It was intended to transplant 2 to 3 seedlings/hill with a hill to hill distance of 15 cm and row spacing of 20 cm with not more than 5 % missing hills and 1% seedling damage.

It comprised a seedling box and ejector, a pair of picker sets actuated by a stationary cam and a planting finger to plant the seedlings released by the pickers. The main shaft carrying the picker sets could be driven by a ground wheel using human, animal or mechanical power.

The laboratory tests to study the performance of picking and releasing the seedlings, had shown that as the rate of picking increased, the missing hills, seedling damage and power consumption increased, while average number of seedlings/hill decreased. However, upto a picking rate of 120 hills/min. the missing hills were 5.69%, average number of seedlings/hill, 2.1 and seedlings damage, less than 1%. As the seedling height was reduced from 30 to 20 cm the average number of seedlings/hill increased from 2.1 to 2.4 at this picking rate. It was found that on an average 125 man hrs/ha were required to wash and load the seedlings. The limited trials in the field indicated that further improvement in the planting finger is needed as the seedlings were not planted erect.

DEDICATED

TO

MY PARENTS

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(C.P. Muhammad)

TABLE OF CONTENTS

CHAPTER	DESCRIPTION	PAGE
	ACKNOWLEDGEMENTS	v
	LIST OF FIGURES	x
	LIST OF TABLES	xiv
	SYMBOLS AND ABBREVIATIONS	xv
I	INTRODUCTION	1-7
II	REVIEW OF LITERATURE	8-57
2.1	Development of Paddy Transplanting Machines	8
2.1.1	Transplanting aids and semi-automatic transplanters	9
2.1.2	Transplanters with picking and planting fingers	14
2.1.2.1	Transplanters using conventional seedlings	16
2.1.2.2	Transplanters using non-conventional seedlings	30
2.1.3	Some innovative approaches for paddy transplanting	43
2.2	Agronomic Aspects of Paddy Transplanting	52
III	MATERIALS AND METHODS	58-95
3.1	Design Considerations and Development of the Transplanting Mechanism	59
3.1.1	Seedling holding and conveying system	61

3.1.1.1	Seedling box	61
3.1.1.2	Seedling conveying system	63
3.1.2	Seedling picking and releasing system	74
3.1.2.1	Seedling picker-sets	74
3.1.2.2	Main frame and stationary cam	77
3.1.3	Seedling planting system	80
3.1.4	Constructional details of mechanism-B	82
3.3	Test Set-up and procedures	84
3.3.1	Laboratory test set up	84
3.3.1.1	Variable speed drive	87
3.3.1.2	Conveyor arrangement	87
3.3.2	Test procedure	88
3.3.2.1	Preparation of seedlings	88
3.3.2.2	Method of the test	90
3.3.3	Test conditions and variables studied	91
3.3.4	Field test	95
IV	RESULTS AND DISCUSSION	96-129
4.1	Effect of Rate of picking	96
4.1.1	Seedling distribution	96
4.1.2	Plant hill missing	109
4.1.3	Seedling damage	112

4.1.4	Power consumption	115
4.2	Effect of Height of Seedling	115
4.2.1	Seedling distribution	115
4.2.2	Plant hill missing	117
4.2.3	Seedling damage	118
4.2.4	Power consumption	118
4.3	Effect of the Mechanisms	118
4.3.1	Seedling distribution	118
4.3.2	Plant hill missing	119
4.3.3	Seedling damage	120
4.3.4	Power consumption	124
V	SUMMARY AND CONCLUSIONS	130-134
	SUGGESTIONS FOR FUTURE WORK	135
	REFERENCES	136
	APPENDICES	

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LIST OF FIGURES

FIGURE NO.	DESCRIPTION	PAGE
1.1	Area and production of rice in India	2
1.2	Manual transplanting of paddy in India	5
1.3	Machine transplanting of paddy in Japan	5
2.1	Hand transplanting aid	10
2.2	Semi-automatic transplanter	10
2.3	Semi-automatic transplanter in operation	11
2.4	Three-row transplanting aid	13
2.5	Transplanter platform	15
2.6	Hand-operated Chinese transplanter	15
2.7	Hand-operated double tray transplanter	17
2.8	Animal-drawn 4-row transplanter	17
2.9	Manually-operated paddy transplanter	19
2.10	Power-tiller attachement for transplanting paddy	21
2.11	An improved tiller attachment for transplanting paddy	21
2.12	Operation of the take out and planting arms of improved attachment	21
2.13	Annapurna paddy transplanter	23
2.14	Bullock-drawn paddy transplanter	23
2.15	An experimental paddy transplanter	27
2.16	A 12-row Chinese transplanter	27

2.17	A 6-row Korean transplanter	29
2.18	A seedling plucker for conventional nursery	29
2.19	Seedling boxes for unconventional nurseries	32
2.20	Transplanting machine for soil bearing seedlings	32
2.21	Transplanting machine with float	35
2.22	Cutting and planting of band type nursery	35
2.23	A self-propelled transplanting machine for mat type nursery	37
2.24	Movement of the seedling placing board	37
2.25	Link mechanism of the planting fork for mat type nursery	39
2.26	Types of planting forks for mat type nursery	39
2.27	Tractor-mounted paddy transplanter	42
2.28	Ground-wheel driven transplanter	42
2.29	Handai tractor-mounted transplanter	44
2.30	The I.R.R.I.-manual transplanter for mat type nursery	44
2.31	Paper pots for paddy seedlings	48
2.32	Soil stuffing and seeding machine for paper-pot seedlings	48
2.33	Hand-broad casting of paper-pot seedlings	49
2.34	Semi-automatic planter for paper-pot seedlings	49
3.1	Paddy transplanting mechanism-complete view	62
3.2	Details of the seedling box and its opening	64

3.3	Details of the belt and screw conveyors	66
3.4	Mounting details of the seedling conveyors	68
3.5	Details of the seedling rake	69
3.6	Seedling rake- plan view	70
3.7	Details of the seedling ejector	72
3.8	Operation of the seedling ejector	73
3.9	Details of the seedling picker assembly	75
3.10	Grasping and bringing the seedlings by pickers	76
3.11	Releasing the seedlings by pickers	78
3.12	Paddy transplanting mechanism-A	79
3.13	Operation of the planting finger	81
3.14	Paddy transplanting mechanism-B	83
3.15	Laboratory test set-up	85
3.16	Laboratory test set-up in operation	86
3.17	Part of the conveyor holding seedlings hills	89
3.18	Damaged seedlings	89
4.1	Effect of rate of picking on seedling distribution for mechanism-A (seedling height-30cm)	99
4.2	Effect of rate of picking on seedling distribution for mechanism-A (seedling height-25 cm)	100
4.3	Effect of rate of picking on seedling distribution for mechanism-A(seedling height-20 cm)	101
4.4	Effect of rate of picking on seedling distribution for mechanism-B (seedling height-30cm)	102

4.5	Effect of rate of picking on seedling distribution for mechanism-B (seedling height-25 cm)	103
4.6	Effect of rate of picking on seedling distribution for mechanism-B (seedling height-20cm)	104
4.7	Seedling distribution at various rate of picking (mechanism-A, seedling heights 30 and 25 cm)	105
4.8	Seedling distribution at various rates of picking (mechanisms-A and B, seedling heights 20 and 30 cm respectively)	106
4.9	Seedling distribution at various rates of picking (mechanism-B, seedling heights 25 and 20 cms)	107
4.10	Effect of rate of picking on average number of seedlings/hill at various seedling heights	108
4.11	Effect of rate of picking on plant hill missing for the two mechanisms	111
4.12	Effect of rate of picking on seedling damage for the two mechanisms	114
4.13	Effect of rate of picking on power consumption for the two mechanisms	116
4.14	Velocity diagram at the point of picking for mechanism-A	122
4.15	Velocity diagram at the point of picking for mechanism-B	123
4.16	Effect of tip -velocity of pickers on average number of seedlings/hill, missing, damage and power consumption	126
4.17	Locus of the picker tip for mechanism-A	129

o o o o o

LIST OF TABLES

TABLE NO.	DESCRIPTION	PAGE
2.1	Specifications of transplanters tested in Japan in 1975	40
2.2	Agronomic recommendations for paddy transplanting	54
3.1	Test conditions and variables	94
4.1	Analysis of variance for average number of seedlings/hill	98
4.2	Analysis of variance for plant hill missing	110
4.3	Analysis of variance for seedling damage	113

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SYMBOLS AND ABBREVIATIONS

A	Ampere
a.c	alternating current
agric.	agricultural
Agron.	Agronomy
Am.	American
Assn.	Association
Av.	Average
Bull.	Bulletin
Cent.	Centre
cm	Centimetre
Co.	Company
Coll.	College
Conf.	Conference
Contd.	Continued
cps	cycles per second
Dept.	Department
Dev.	Development
d.f	degrees of freedom
Engng.	Engineering
Engrs.	Engineers
Eqp.	Equipment
Exp.	Experiment

Fac.	Faculty
F.A.I.	Fertiliser Association of India
F.A.O.	Food and Agricultural Organisation
Fig.	Figure
Figs.	Figures
gm	gram
ha	hectare
hp	horse power
hr	hour
hrs	hours
I.C.A.R.	Indian Council of Agricultural Research
I.I.T.	Indian Institute of Technology
Inst.	Institution
Int.	International
I.R.R.I.	International Rice Research Institute
J.	Journal
K.A.U.	Kerala Agricultural University
kcal	kilo calorie
kg	kilogram
kmph	kilo metre per hour
kwh	kilo watt hour
m	metre
min	minute
mm	milli metre
M.S.	Mild Steel
M.S.S.	Mean Sum of Squares
Natl.	National

N.I.A.E.	National Institute of Agricultural Engineering
No.	Number
p.	page
pp.	pages
Pap.	Paper
P.A.U.	Punjab Agricultural University
Prefect.	Prefecture
p.t.o	power take off
Rep.	Report
Res.	Research
RNAM	Regional Net work of Agricultural Machinery
rpm	revolutions per minute
Sci.	Science
S.D.	Standard deviation
sec	second
Soc.	Society
sq.	square
S.S	Sum of squares
Stn.	Station
Trans.	Transactions
Univ.	University
U.S.A.	United States of America
v	volt
0	degree
*	Statistically significant at 5 per cent level
/	per

Chapter I

INTRODUCTION

Rice is the staple food of approximately half of the world's population. In the International Rice Year celebrated under the auspices of the United Nations in 1966, it was described as the 'grain of life', and the emblem of the celebrations carried the monogram 'Freedom from Hunger', which bore testimony to the importance of rice as an important food material on the international horizon. Rice produces maximum calories per unit area of land among the cereals and is adaptable to a wide agro-climatic conditions.

India, the country having the oldest known rice specimen of the world, is also the second largest rice producer, with an estimated annual cultivated area of 38.6 million hectares and production of 43.8 million tonnes of rice (76). The area and production of rice in India for the last one decade ending 1977, are shown in Fig. 1.1.

Among the various methods of raising rice crop, western countries have adopted direct seeding, as the labour is scarce and costlier and the area is extensive, but in the South-East Asian countries where 90 per cent of the world's rice is grown and consumed, two third of the rice is still transplanted under water availability conditions, despite its higher labour requirements (12).

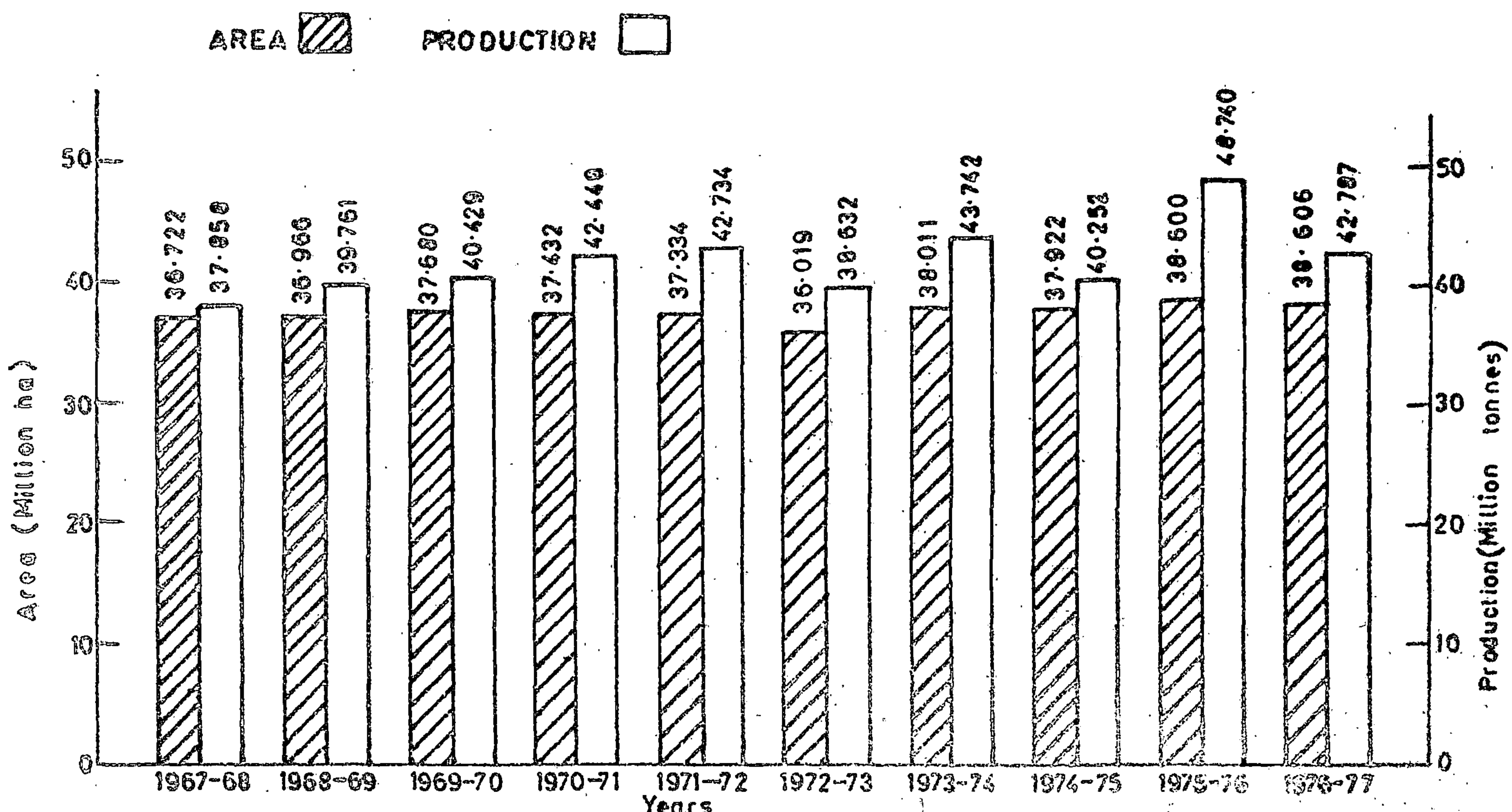


FIG. 1.1. AREA AND PRODUCTION OF RICE IN INDIA (76, 77)

Transplanting which essentially refers to the planting of seedlings grown in a nursery, in the prepared field with the recommended plant hill density, has a series of advantages like (i) the occupation time of the field is 2 to 4 weeks less than with direct seeding (ii) less seed requirement (iii) permits rearing healthy seedlings in the nursery (iv) helps the plant a better start over the weeds due to thorough cultivation and homogeneous puddling (v) invigorates the plants when planted by putting forth fresh roots in all directions with an extended root system thus facilitating a better utilisation of plant food from all around (vi) less sensitive to drought and heavy rainy conditions (vii) allows better water management preventing percolation (viii) allows easy weeding and other intercultural operations (ix) permits optimum plant spacing, which is critical for higher yields and (x) ensures a uniform stand preventing tendency for lodging(41).

The advantages of machine transplanting are well-known. It provides relief from a tedious and awkward bending posture, avoids dipping of the fingers in the puddled soil and reduces the human energy expenditure. Vos (80) reported that in bending posture similar to that followed in paddy transplanting, an extra energy expenditure of about 2 Kcal/min and heart-rate increase of 35 per cent was required. Some other known advantages of machine transplanting are (a) uniform and desired plant hill density and depth of planting (b) saving in labour during peak period (c) timeliness of operation and (d) line transplanting at no extra cost making weeding and interculture easier.

In India, transplanting of rice is still done by manual labour, mostly the hired labour. The bunch of seedlings is held in the left hand and 2 to 4 seedlings separated by the right hand are fixed in the puddled field. This obviously is quite tiresome, inconvenient and irritating to workers. Garg and Singh (70) reported that the number of hills per square metre in the paddy transplanted by hired labour ranged from 18 to 28 as against the recommended about 33 hills per square metre. Saini (64) also reported that 90 per cent of the 1000 fields surveyed in Punjab, had less than 30 hills per square metre. The labourers paid on the basis of area covered known to keep plant hill density low in the centre of the field. The human error also increases exponentially with the rate of planting. Huang and Splinter (22) reported that from the human engineering point of view, the maximum transplanting speed should be limited to 2.4 kmph, while the contract labourers attempt to exeed this limit to a bid to cover more area. Fig. 1.2 shows a typical paddy transplanting scene on an Indian farm.

FIG. 1.2 Manual transplanting of paddy in India

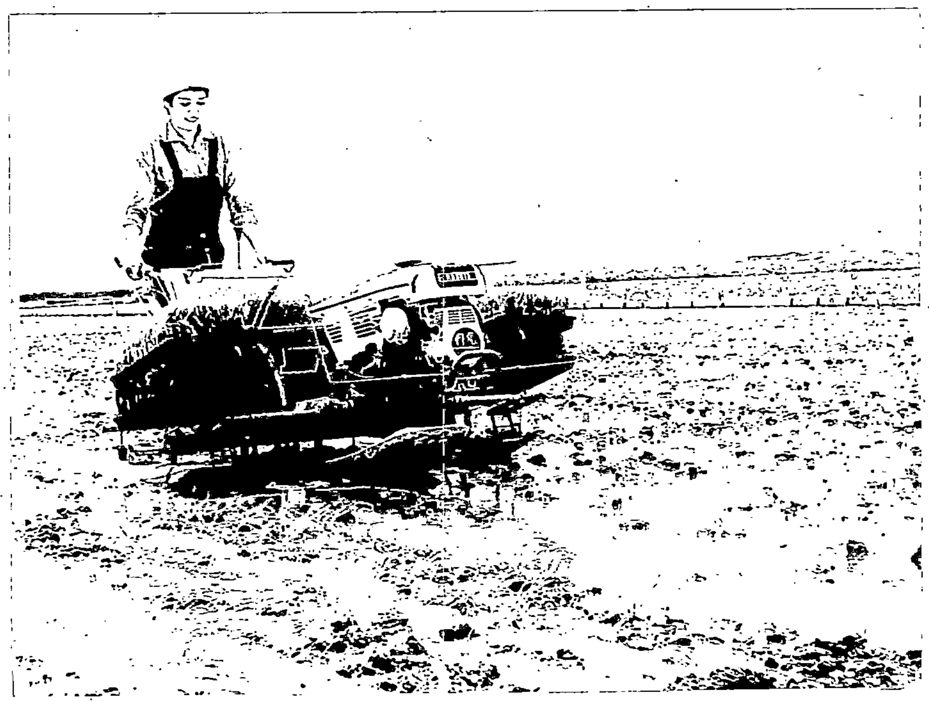


FIG. 1.3 Machine transplanting of paddy in Japan

In the area of wet-rice cultivation, Japan happens to be the most mechanised country in Asia and the world. It has an average yield of 6, 185 kg/ha as against 1,877 kg/ha of India (77). Japan has halved the total labour requirement for paddy cultivation from 212 man-days to about 100 man-days, in which the labour for transplanting has been reduced from 30 man-days to 15 man-days with the use of machine transplanting (18). In 1976 as many as 1.07 million transplanting machines were reported to be in use in Japan. Also of the total 2.724 million hectares of paddy area, 80.4 per cent was mechanically transplanted (37). Fig. 1.3 shows a typical machine transplanting on a Japanese farm. The total labour-requirement for wet-rice cultivation in India is reported to be varying from 133 to 181 man-days/ha, under conventional method, out of which 25 to 30 man-days are for transplanting alone (56, 71). In certain countries like Senegal, transplanting requires 45 man-days/ha (14).

Although Japanese machines are functionally satisfactory, there are many problems like complex mechanism, high initial and running cost, difficulty in coping with the field and seedling conditions, and difficult technique of seedling raising (16,67). These are beyond the capacity of an average farmer of conservative nature and make the Japanese machines unsuitable for Asian farms.

Considerable progress has been made in the area of direct seeding of paddy in conjunction with chemical weed control, yet transplanting continues to be the most widely accepted method in India and most other Asian countries. Hence efforts to develop paddy transplanting mechanisms and devices for conventional seedlings continue to be of considerable interest to the farmers in India and other rice-growing countries. It was, therefore, decided to develop and test a paddy transplanting mechanism for conventional seedlings, which should be versatile enough to operate with human, animal and mechanical power sources.

The following objectives were set for the research reported in this thesis:

1. To design and develop a mechanism for transplanting conventional paddy seedlings.
2. To test the transplanting mechanism under laboratory conditions.
3. To identify the parameters and establish their range for optimal operation of the unit designed under objective (1).

working environment, increased resting time and reduced mental load for safe and precise work (78). Manual transplanting of paddy is quite tedious. Besides, approximately 30 per cent of the total labour required for rice production is accounted for transplanting (29). Attempts made to evolve different mechanisms for paddy transplanting have been briefly reviewed.

2.1.1 Transplanting aids and semi-automatic transplanters

Although, it was hardly a decade back that the transplanting machines were successfully introduced in Japan, the dream of mechanizing this difficult operation had bloomed in the minds of Japanese farmers towards the end of nineteenth century, when the first patent for a transplanter was obtained in 1898 (68). However, the first transplanting device was used in Taiwan in early ninteen fifties (13, 71). It was a simple aid consisting of an iron rod with a fork forged at one end. A wooden handle was fitted at the other end. It had a length of 45 cm (Fig. 2.1). Two to four plants were slipped on to the fork and the tool was inserted into the mud and then withdrawn leaving the seedlings in the puddled soil. This contributed to increased rate of transplanting by about 20 per cent but as it required considerable skill and experience it soon became obsolete. The major drawback that the depth of planting could not be sensed by the operator, was overcome by adding a small base plate, but it still did not become popular.

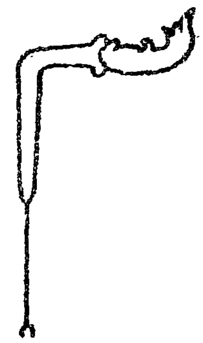
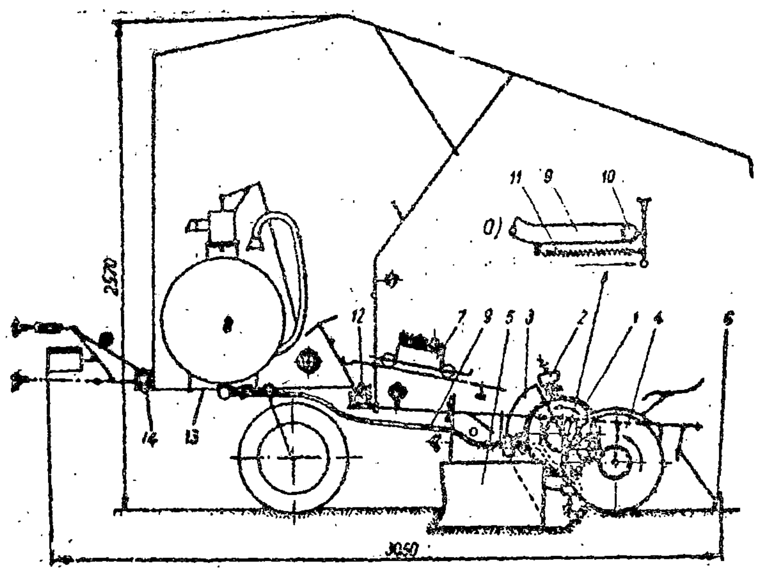


FIG. 2.1 HAND TRANSPLANTING AID (FAO, 1966).



1 — disk with grabs; 2 — grabs; 3 — cam closing the grabs; 4 — press- and disk-driving wheel; 5 — opener; 6 — coverer; 7 — cart holding seedlings; 8 — water container; 9 — elastic hose; 10 — ball valve; 11 — valve-pressing spring; 12 — cross beam; 13 — platform; 14 — support beam; a) detail of an automatic water-sprinkling device.

FIG. 2.2 SEMI-AUTOMATIC TRANSPLANTER (Bernacki et al, 1972)

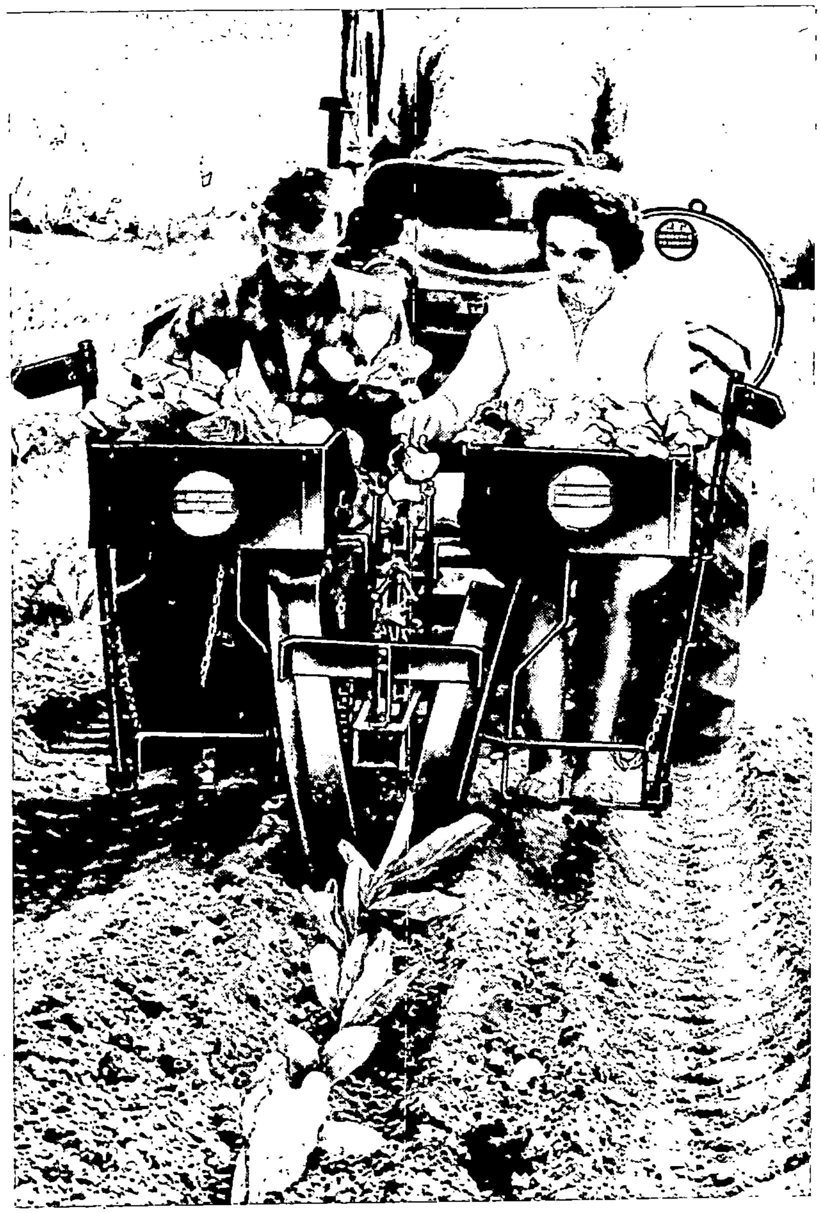
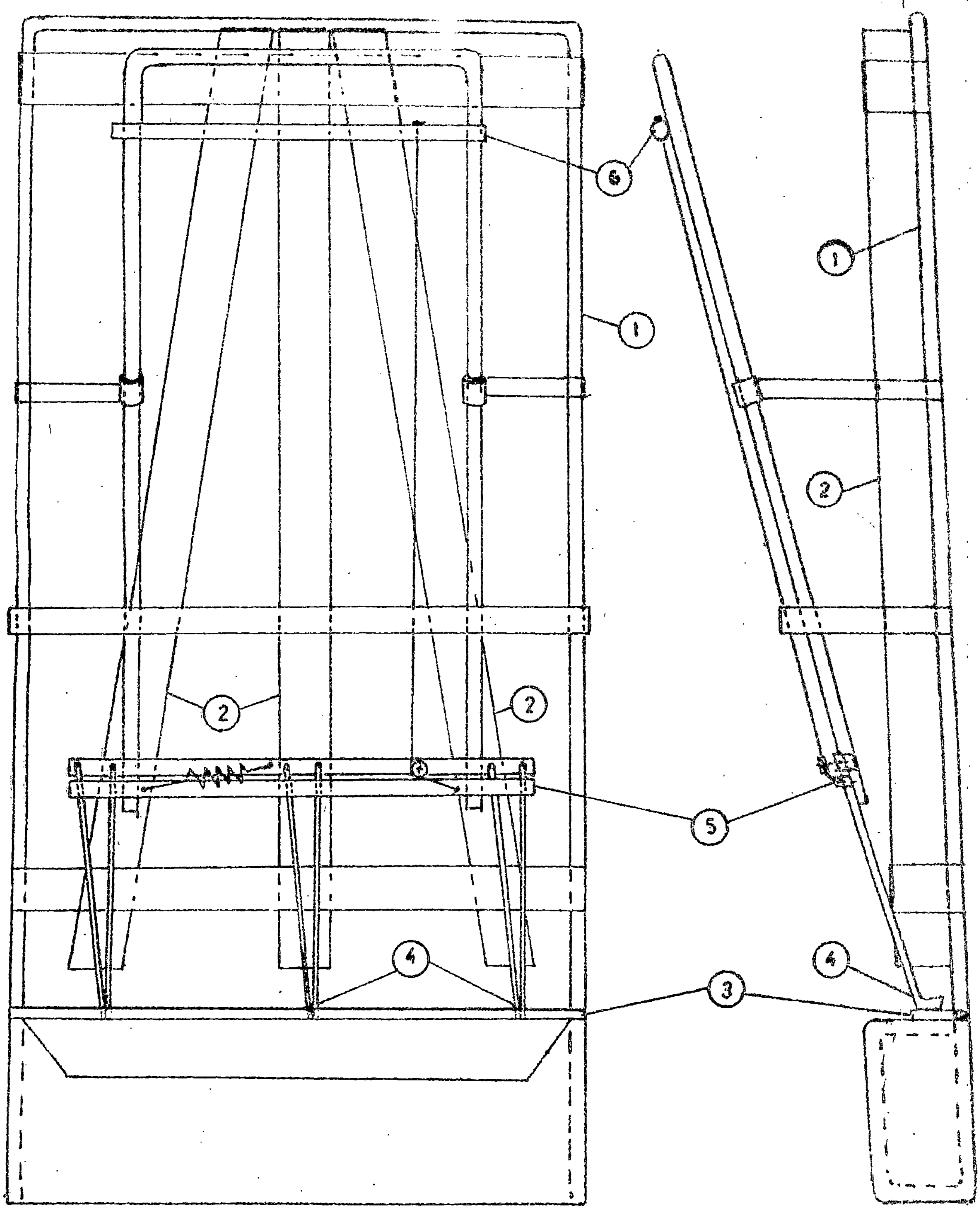


FIG. 2.3 Semi-automatic transplanter in operation (Mechanical Transplanter Co., U.S.A., 1979)

Semi-automatic machines were developed for transplanting seedlings of crops like tomatoes, tobacco, cabbage etc. in western countries (3). Their principle of operation is shown in Fig. 2.2. Usually drawn by a tractor, such a device consisted of a furrow opener, a revolving disc with a series of rubber padded grabs at its periphery and a pair of press-wheels. The workers sitting on the seat provided, picked the seedlings from the container and placed them upside down between grab jaws opened by a stationary cam. The seedlings were taken to the furrow and planted in an erect position. The press-wheels compacted the surface to ensure firm planting of the seedlings (Fig. 2.3). Used under dry field conditions, these machines were sometimes provided with a water tank and automatic valve system to water the seedlings being transplanted.

A three-row transplanting aid for paddy was designed at I.I.T., Delhi (43). It consisted of a main frame, three seedling-dropping tubes, a spring loaded and hinged seedling retainer at the bottom, three planting fingers and an actuating mechanism (Fig. 2.4). The device and seedling tray were suspended from the neck of the operator who picked a few seedlings and dropped them through the tubes. These remained upright on the retainer plate. On lifting the handle of the actuating mechanism, the fingers were opened to grasp the dropped seedlings. The finger assembly was then moved downward



1. Main frame
2. Seedling tubes
3. Seedling retainer
4. Planting fingers
5. Finger actuating mechanism
6. Handle for '5'

FIG. 2.4. THREE-ROW TRANSPLANTING AID (Mandhar, 1975)

and the fingers were again opened to leave the seedlings erect in the soil. This device was reported to require about 300 man-hours/ha which practically saved no labour.

Ben-Nun (2) reported the design of a wooden rice transplanter platform that could be drawn over the paddy field by a single animal (Fig. 2.5). It was 240 cm long, 70 cm wide and 12 cm high with eight adjustable pegs for marking underneath. The persons sat on the platform in cross-legged posture. A worker picked up 6 to 8 seedlings from the bunch kept on his lap, divided them into two halves and then transplanted by both hands in two adjacent markings left by the pegs. It was claimed that four trained workers and a driver could do the work of fifteen labourers (2).

2.1.2 Transplanters with picking and planting fingers

Transplanters belonging to this category are mechanical contrivances designed to replace the human fingers by mechanical fingers, which pick up the required number of seedlings from a tray and plant them in the puddled field, similar to hand-transplanting. These are of two types. One, using washed-root seedlings (conventional) and, the other, using non-conventional seedlings, i.e. band-type, continuous band-type or mat-type seedlings raised in a special nursery using trays or other frame work.

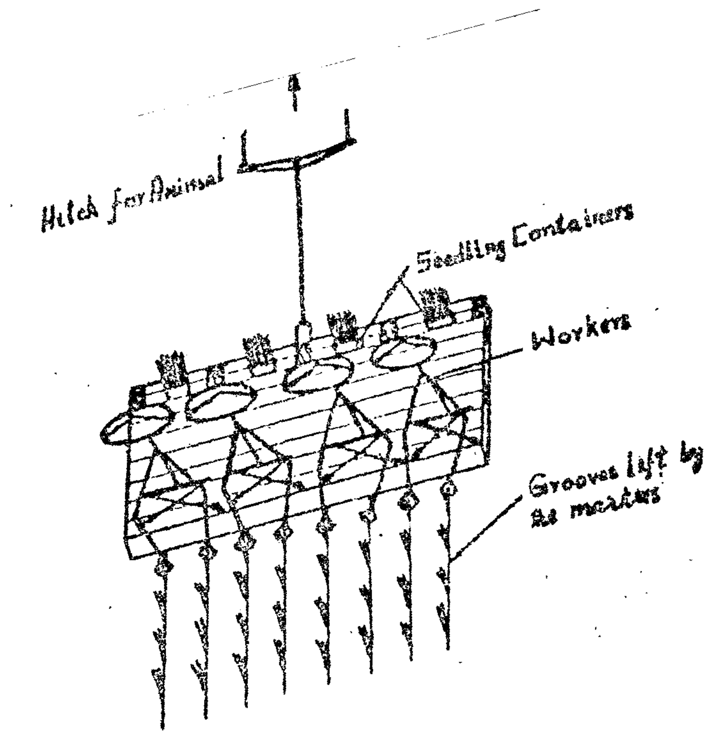


FIG. 2.5 TRANSPLANTER PLATFORM (Ben-Nun Raanen, 1975)

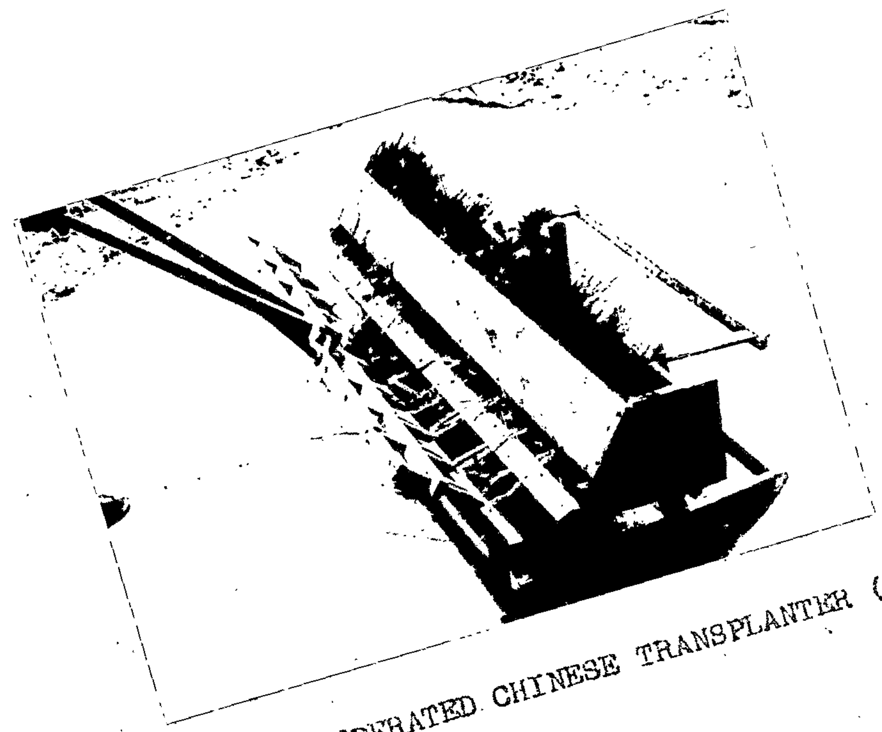


FIG. 2.6 HAND-OPERATED CHINESE TRANSPLANTER (FAO, 1966)

2.1.2.1 Transplanters using conventional seedlings: Stout (13) described a Chinese hand-operated transplanter (Fig. 2.6). It consisted of a box to hold the seedlings, mounted on a sledge platform. A movable partition pushed the seedlings to the rear of the box. A set of seven pincers, controlled by the operator through the pivoted pair of handles, grasped the seedlings from the box and forced them into the puddled ground. A similar machine was contemporarily developed in Japan had the same method of operation (13).

These machines are reported to have failed due to the following reasons:

1. These were uneconomic - the increase in rate of planting was insufficient to justify their cost.
2. The plants did not set in the mud; after opening, the pincer did not release the plant properly.
3. The number of plants set varied considerably especially when there was variation in plant size.
4. Wastage of plants often resulted from root entanglement; plants were pulled out of the box and lost before being properly set.

A two-row manually operated transplanting mechanism was tried at Coimbatore in 1962 (63). It had eight tweezer-type pickers (Fig. 2.7) and its working was similar to the Chinese

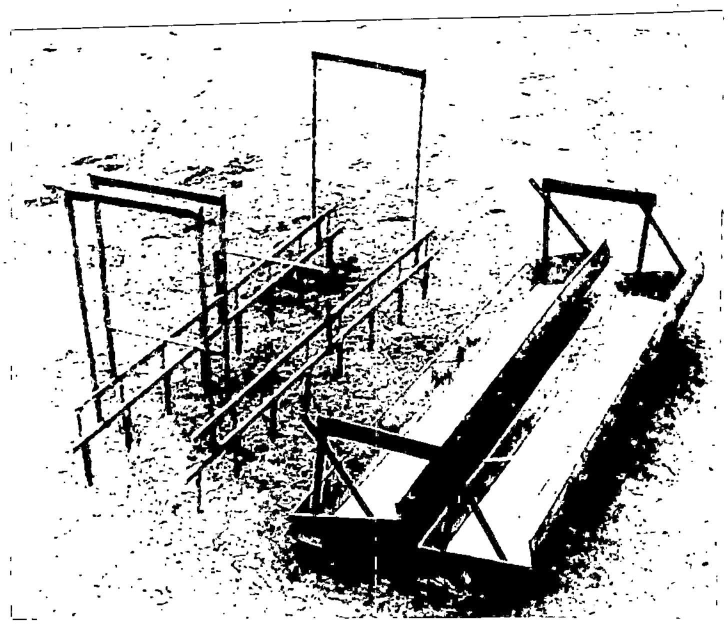


FIG. 2.7 Hand-operated double tray transplanter (RNAM, 1979)

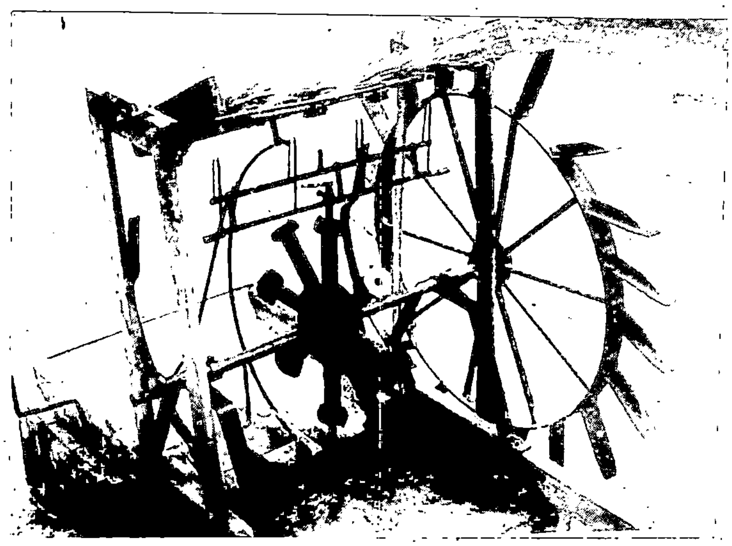
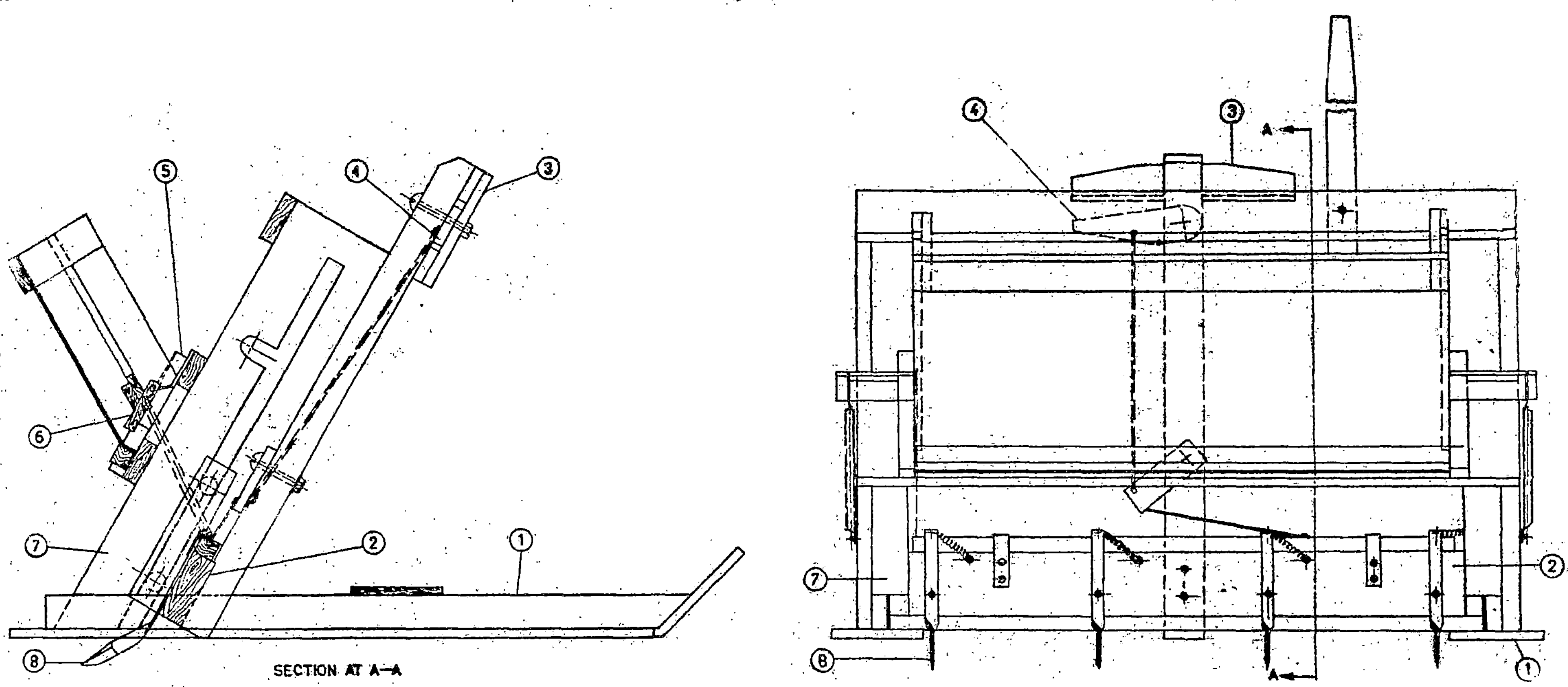


FIG. 2.8 Animal-drawn 4-row transplanter (RNAM, 1979)

version. As the performance was not satisfactory, it was abandoned and the development of a 4-row animal-drawn transplanter was taken up (63). This consisted of a shaft driven by the ground-wheel which carried 8 radial cylinders (Fig. 2.8). At the end of each cylinder, four pickers were fixed parallel to the shaft. A wire comb was fixed inside the seedling tray to keep the seedlings in position. The tray was moved to and fro. As the pickers entered the tray, they picked the seedlings, and planted them in the soil, when they reached the bottom most position. This mechanism was reported to be needing further improvements for satisfactory functioning (63).

A four-row wooden paddy transplanter was developed in 1964 by N.I.A.E. (13, 49, 71). It consisted of a float which carried the main frame with two members on either end. These members had grooves at their inner side through which a horizontal member, with four-sets of fingers could slide up and down by manually lifting and lowering the handle fitted to it. A lever provided at the upper end of this handle actuated the fingers to pick the seedlings from a box, and to release them in the soil (Fig. 2.9). A spring loaded movable plate pushed the seedlings towards the opening of the seedling box. This transplanter was also tested at Tractor Training and Testing Centre, Budni in 1966 and its capacity was reported to be 2 acres/day under optimum field conditions (71,79). However, labour saving was substantially reduced due to loss of time in



1. FLOAT 2. SLIDING MEMBER 3. HANDLE 4. LEVER 5. SEEDLING BOX 6. SEEDLING PRESSING PLATE 7. SIDE MEMBER 8. PICKERS

FIG.2.9.MANUALLY OPERATED PADDY TRANSPLANTER (N.I.A.E, 1964)

washing, pruning and arranging the seedlings in the box and periodical cleaning of the fingers against sticking soil.

Miura (46) reported a power-tiller operated machine introduced in Japan in 1965 (Fig. 2.10). It used washed-root, conventional seedlings which were kept in the upright position in the seedling box. On engaging the clutch, the planting claw moved to the seedling box and grasped a hill of seedlings, pulled them out and transfered to the ground levelled by a board attached to the mechanism. The claw opened on touching the ground leaving the seedlings erect and then returned to its original position to repeat the operation. A device to check the taking out of unwanted seedlings due to root entanglement was provided. The seedling box was moved transversely after every picking so that the claw could grasp new seedlings regularly. This had six different sizes of interchangeable claws to accomodate different seedling diameters to ensure correct number of seedlings per hill. The depth of planting was adjusted by moving the levelling board up or down with the help of a turn buckle. The row to row distance was 30 cm, while the hill to hill distance was adjustable from 12 to 18 cm, by changing the belt pulley. Satisfactory performance, at a rate of 100 to 120 hills/min per row, requiring 30 to 35 hrs/ha, could be obtained only when seedling height was between 18 and 35 cm, root length was less than 5 cm, number of tillers was less

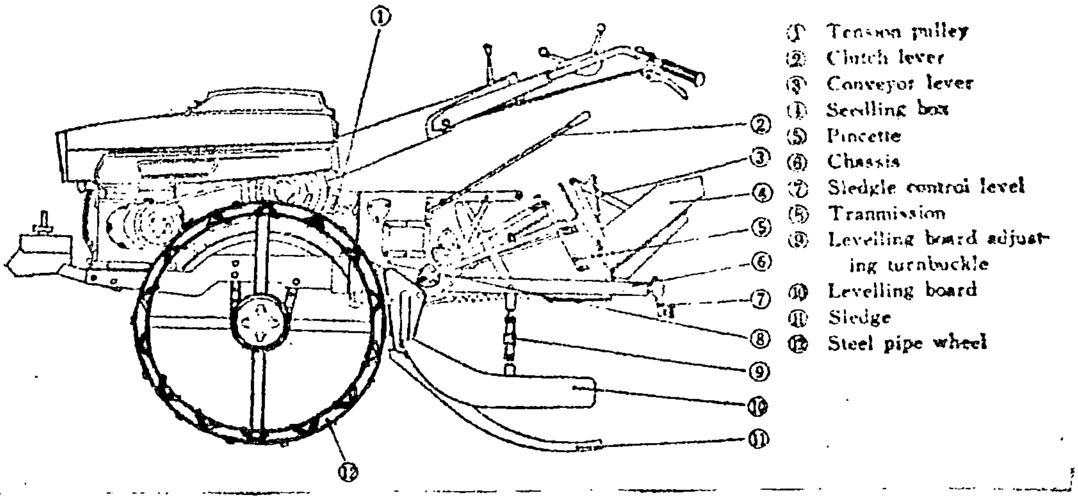


FIG. 2.10 POWER-TILLER ATTACHMENT FOR TRANSPLANTING PADDY SEEDLINGS (Miura, 1966)

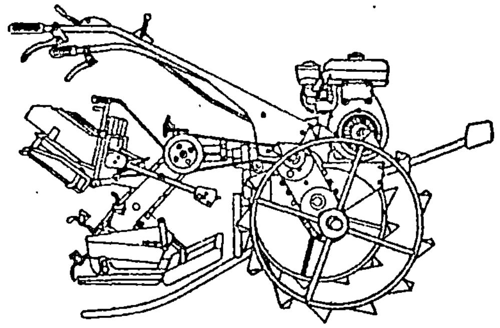


FIG. 2.11 AN IMPROVED TILLER ATTACHMENT FOR TRANSPLANTING PADDY SEEDLINGS (Hoshino, 1969)

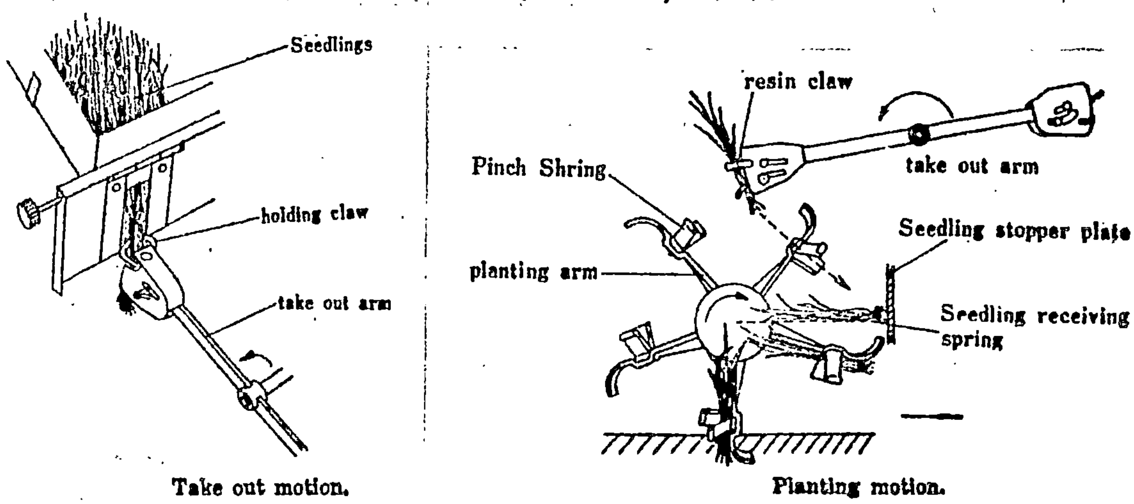


FIG. 2.12 OPERATION OF THE TAKE-OUT AND PLANTING ARMS OF THE IMPROVED ATTACHMENT (Hoshino, 1969)

than two and they were hard, the field was ploughed less than 15 cm, unmatured compost or cut weeds were not strewn on the field surface and the soil was not so hard and compact after about 24 hours of careful puddling. Any change in these conditions resulted in higher percentage of missing, floating of seedlings, improper depth and difficulty in forward movement of the machine.

Hoshino (19) reported a power-tiller driven p.t.o. operated transplanter which was marketed in the sixties in Japan (Fig. 2.11). It was equipped with a rotary take-out arm which picked out 2 to 4 seedlings by its claw and placed them over a 'seedling receiving spring' as shown in Fig. 2.12. These were subsequently received by the 'pinch spring' of the planting arm and planted in the soil. The device could transplant two rows of paddy at 30 cm spacing with an adjustable hill to hill distance of 12 to 18 cm at a rate of 120 to 180 hills/min per row and required 10 to 12 hrs/ha.

Mahapatra (42) developed a ten-row manual device known as Annapurna Paddy Transplanter. It resembled the N.I.A.E. design in construction and operation. Made of iron and wood, it measured 100 cm in length, 10 cm in width, 60 cm in height and weighed 35 kg (Fig. 2.13). The base of the device served as a float and carried a detachable seedling tray. The ten sets of fingers, when actuated by the

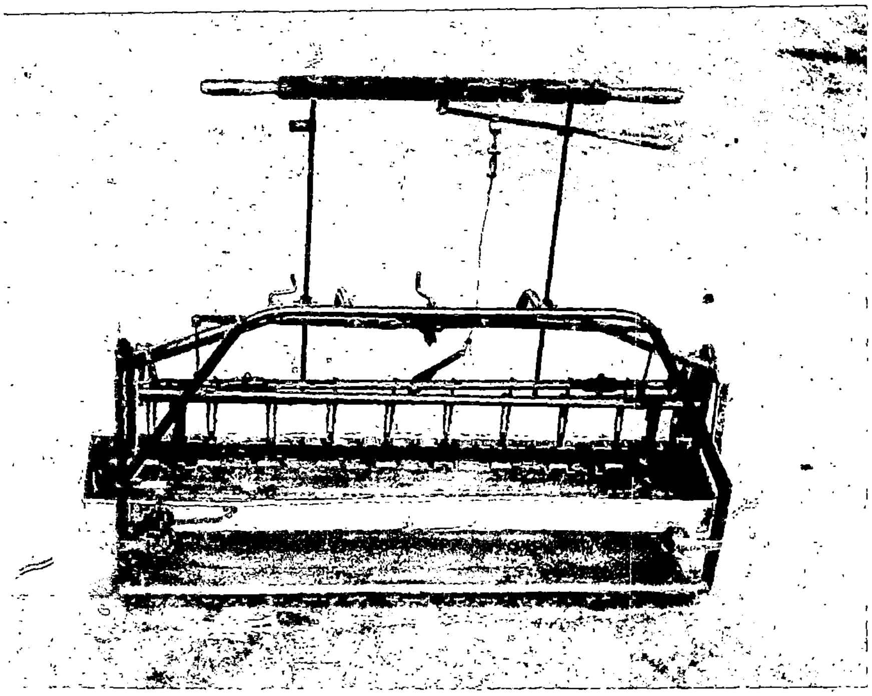


FIG. 2.13 ANNAPURNA PADDY TRANSPLANTER (Mahapatra, 1973)

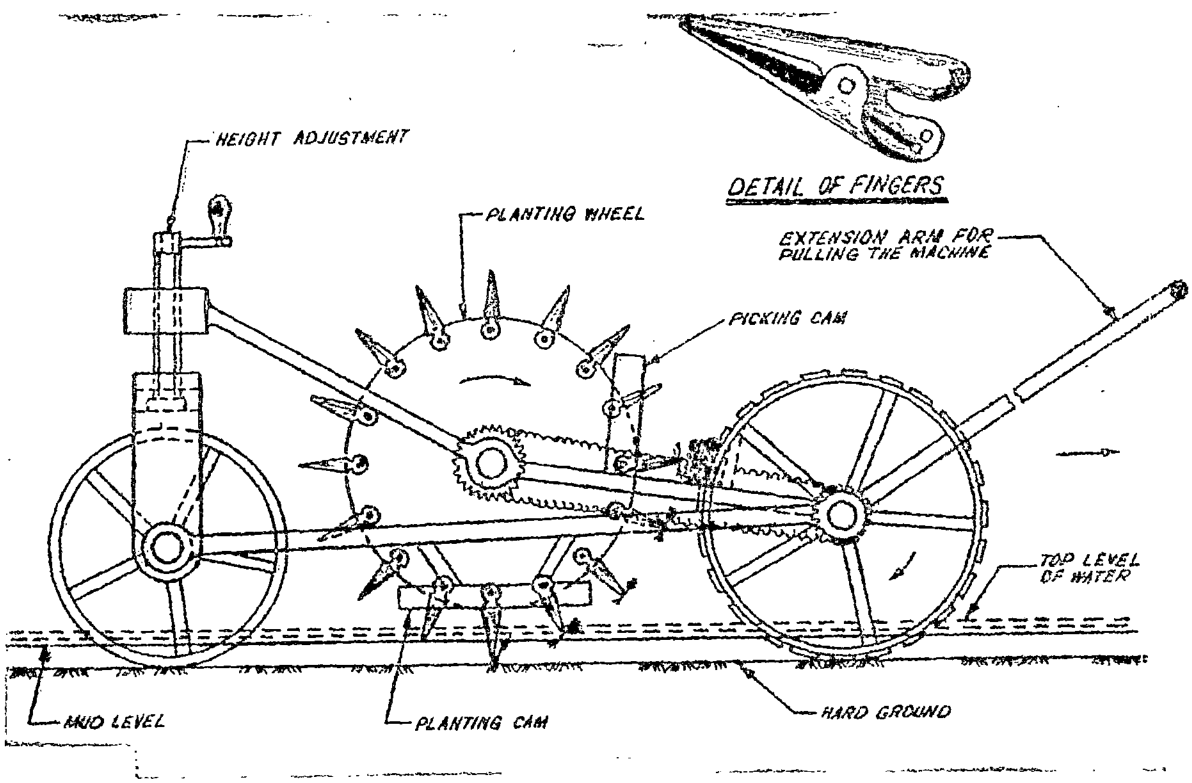


FIG. 2.14 BULLOCK-DRAWN PADDY TRANSPLANTER (Sandhu, 1975)

operator through the linkages fitted on the handle, passed through a feeder set, picked seedlings from the tray, returned and planted them in the soil. Though the feeder set was to keep back the excess seedlings, it was not very effective. A sliding mechanism moved the tray to and fro enabling the fingers to pick up seedlings systematically. A pair of wheels, provided for easy forward movement, had to be removed in puddled and loose soil. It planted the seedling at an adjustable depth of 2 to 4 cm at an angle of about 75° with a hill to hill distance of 10 cm. Row spacing was adjustable around 20 cm. Seedlings of 20 to 30 days age and 15 to 20 cm height with 3 to 4 cm long roots were ideal. Length of stem and roots were cut to the required size. Transplanting could be done in standing water of 1 to 2 cm depth with a puddled depth of 6 to 8 cm. Under ideal field conditions, missing hills of less than 10 per cent was claimed, but in actual field conditions as much as 37 per cent missing and 500 man-hours of labour requirement was reported (70).

Sandhu (66) reported a bullock-drawn mechanism for conventional seedlings. It consisted of a wooden circular disc of 75 cm diameter, with a dozen spring loaded fingers of 15 cm length arranged radially at the periphery. The disc was driven by a ground wheel by means of a chain & sprocket as the mechanism was drawn forward (Fig. 2.14). The seedlings arranged in a box, after cleaning and sizing were gripped and released in the soil by the fingers that were opened and closed by a pair of stationary wooden cams, suitably positioned. The frame work had no float, but a gauge wheel at the rear could be moved up or down to adjust the depth of planting. Though the performance was encouraging, the unpredictable behaviour of the seedlings presented a practically inefficient operation and the designer tried five different seedling feeding mechanisms, namely; (i) seedlings held in a box and pushed at the root by a member loaded by a compression spring, towards the narrow opening at the root level of the box front, (ii) seedlings suspended by hand and arranged by both the hands (iii) seedlings held by clip loaded by a torsion spring with the roots downwards, the clip pressing the middle of the plant (iv) seedlings pressed by the clip but arranged on a horizontal platform that reciprocated roots projecting out of the platform for gripping by the fingers, (this was also tried in vertical position), (v) displacing the picking fingers in a zig-zag manner at the disc periphery, seedlings being fed through a box and retained loosely by a little force at the leaves only. However, observations showed that further improvements were required (66).

Parida and Das (55) reported the laboratory test results of an experimental automatic transplanter developed at I.I.T., Kharagpur. It consisted of a tray to hold and feed the seedlings, a finger mechanism to pick up and release the seedlings, and a mechanism to oscillate the finger assembly between the points of picking and release as shown in Fig. 2.15. The seedling tray of 92 cm x 22 cm x 15 cm size had two compartments inside it, which held the seedlings. By means of a screw feeding system the seedlings were pushed continuously towards the tray opening with the aid of a cam and follower pair and a gear box. The tray moved forward at the time of picking the seedlings and then backward. A set of fingers were mounted on a platform. The finger-head passed through a square shaft, the oscillating motion of which transmitted the power to the finger by two pairs of slider crank arrangements. The square shaft was oscillated by a cam and follower pair, which allowed the fingers to open and close at specific distance along the path of their movement. The platform with the fingers moved up and down by a slider crank mechanism that converted the input crank rotation into reciprocating motion of the finger-head. The stroke was so adjusted that the fingers released the seedlings 5 cm below the soil surface. The overall construction of the mechanism was quite cumbersome employing too many components. Laboratory tests showed that the number of seedlings per hill varied from 1 to 8 and planting was done at angles of 60° to 90° with percentage of missing hills ranging from 12.5 to 21.

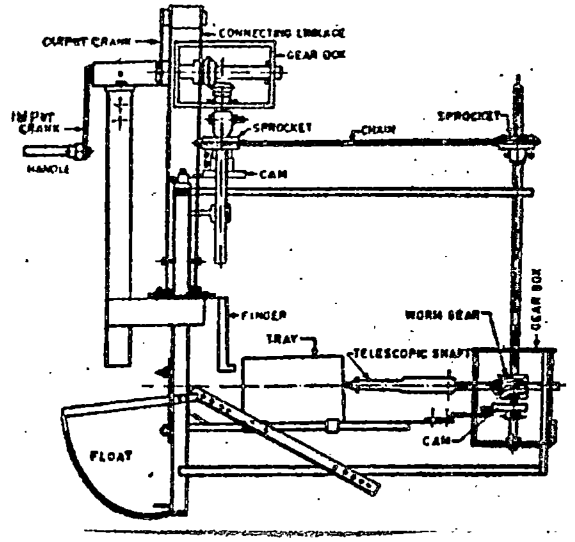


FIG. 2.15 AN EXPERIMENTAL PADDY TRANSPLANTER (Parida and Das, 1977)

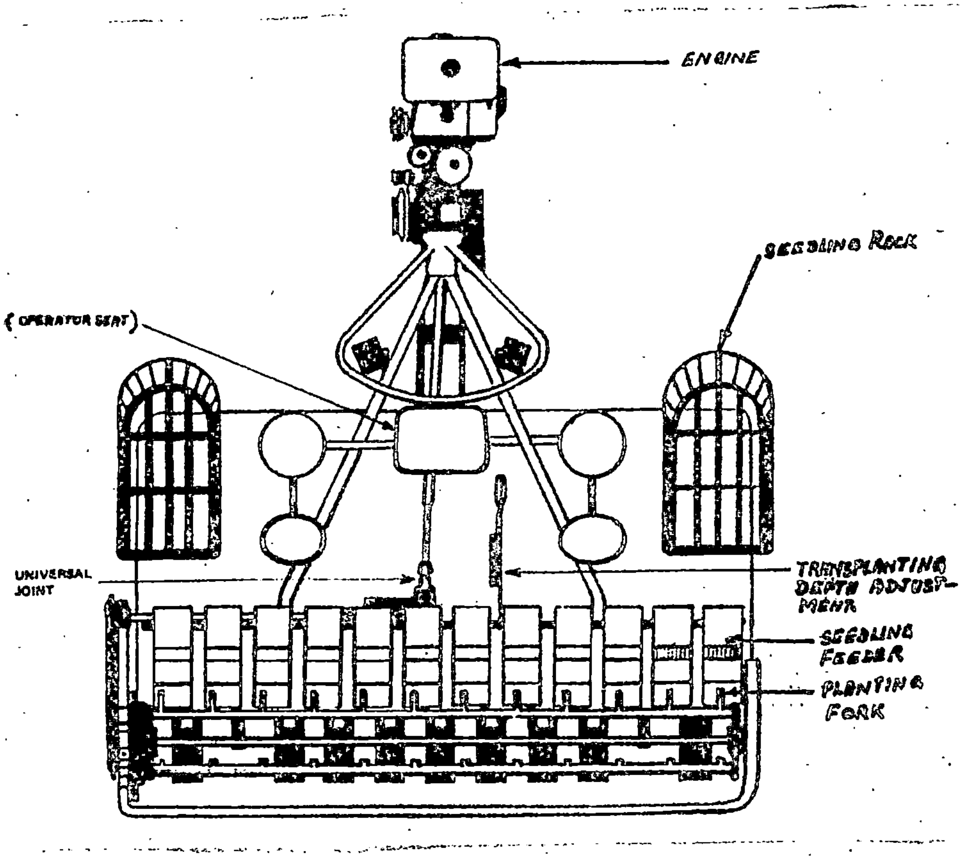


FIG. 2.16 A 12-ROW CHINESE TRANSPLANTER (RNAM, 1979)

A self-propelled 12-row transplanter for seedlings of 20 to 30 cm length with washed and trimmed roots, was reported to be used in China (63). Having a working width of 210 cm, it covered 0.14 to 0.23 ha/hr. The row spacing was adjustable from 10 to 20 cm and planting depth from 3.5 to 7.0 cm. Powered by a 4 hp gasoline engine, its fuel consumption was reported to be 0.5 to 0.8 litre/hr. It weighed 310 kg. The planting unit was hitched to the front frame having engine and steering (Fig. 2.16). For its smooth working, it was reported that the field should be level with standing water of 2 to 4 cm depth.

Further modifications in this machine were carried out in Korea and a 6-row unit was developed (Fig. 2.17). The engine mounting and power transmission of this was so designed that these could be used for other farming operations like weeding spraying, manure distribution etc. also. Weighing 290 kg, it could be worked at speeds of 0.36 to 0.50 m/sec and covered 0.125 ha/hr, with a row spacing of 14 cm. Two persons were required. Problems like excessive number of 3 to 11 seedlings/hill, higher missing hills upto 50 per cent were found in initial trials in Pakistan (35, 30). However, on modification, missing was reported to have been reduced to about 8 per cent. A 7-row animal drawn machine was also reported to be under development in Pakistan (63).

In order to reduce the labour requirement of uprooting the conventional nursery, a seedling plucker was developed in

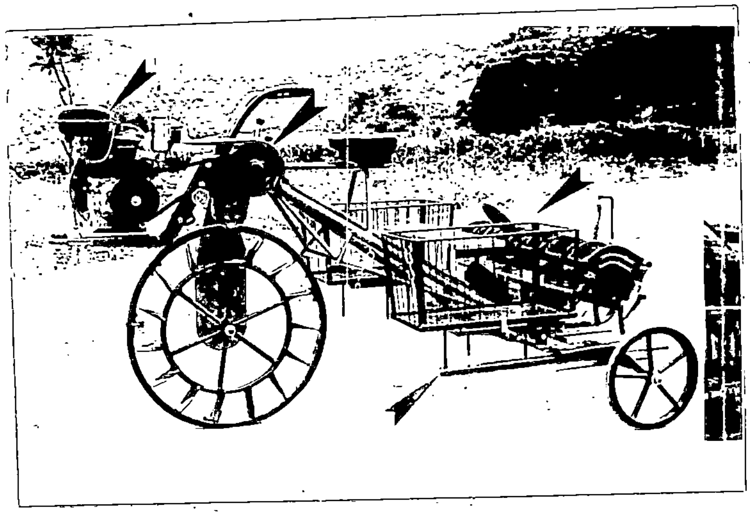


FIG. 2.17 A 6-ROW KOREAN TRANSPLANTER (RNAM, 1979)

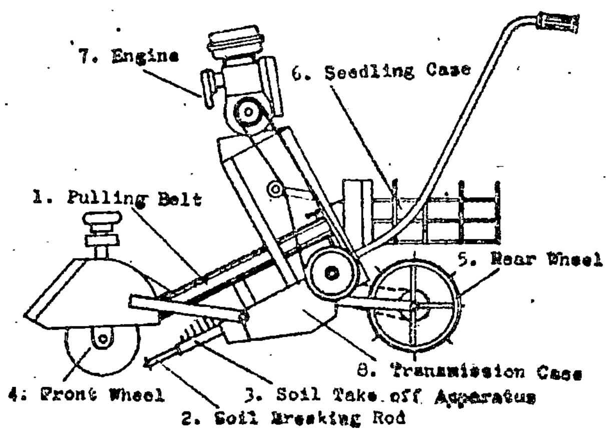


FIG. 2.18 A SEEDLING PLUCKER FOR CONVENTIONAL NURSERY (Hoshino, 1972)

Japan (20). Having an overall dimensions of 115 cm length, 52 cm width, 85 cm height and 35 kg weight, it was adaptable for drilled-nursery with a row spacing of 75 cm and width of 1.0 cm (Fig. 2.18). It was powered by a two-cycle, air-cooled engine of 1.7 hp. The process of plucking consisted of softening the soil around the roots of seedlings and cutting longer roots by the rotating soil breaking rod, grasping, pulling and conveying the seedlings by the pulling-belt moving in the upward direction, and finally storing the seedlings in the seed boxes. The rear wheel drove the machine, while the front wheel helped to adjust the depth of soil breaking and pulling. A soil take-off apparatus to clean the roots was provided below the belt. Two belts moving at different speeds aided in adjusting the posture of seedlings. The machine worked at a speed of 0.36 to 0.54 kmph and took 10 to 15 hrs to pluck the seedlings to be transplanted in 1 ha. A spongy rod type soil take-off arrangement worked well in dry soil, while a comb claw type had to be used for wet soil. Further improvements were reported to be underway.

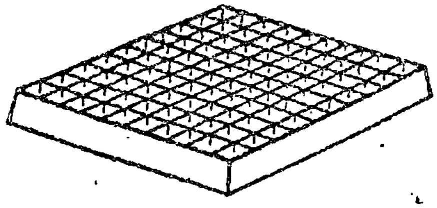
2.1.2.2 Transplanters using non-conventional seedlings: As the reduction of labour was not substantial and the difficulties in performance were unavoidable, the trend in Japan was to raise seedlings with soil. These were called non-washed seedlings and were of four types viz. band-type, continuous band-type, pot-type and mat-type (19). These were raised in boxes. In the band-type, the box was divided by partitions to provide bands of seedlings which were 7 to 10 mm wide. The bands were cut at the time of transplanting, into blocks of 10 to 15 mm length.

In the continuous band-type, the partitions did not span from edge to edge, so that the seedlings when grown took the shape of a continuous band extending from one corner of the box to the diagonally opposite corner (Fig. 2.19). This was also to be cut into blocks at the time of transplanting.

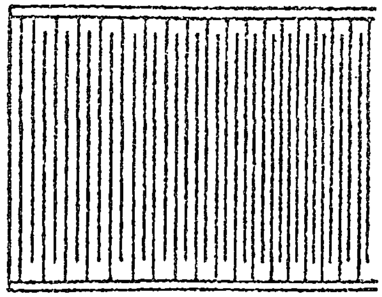
In the pot-type, the box was divided into blocks or pots by lattice like partitions (Fig. 2.19). The seedlings grown in this were ready to use without cutting.

In the mat-type, the box was kept open without any partition and the seedlings grew like a mat, with their roots interwoven. The transplanting unit had a cutting edge to slice out blocks of seedlings from the mat.

The non-washed seedlings were raised in green houses on a co-operative basis. A green house of 9.6 m x 4.56 m size made of steel structure and covered with 0.5 mm polythylene sheet could cater the need of 30 ha of field in 15 days (39). Accurate planters for uniform seeding and steam or electric germinators to ensure maximum germination were invariably employed, as the characteristics of the nursery determined the

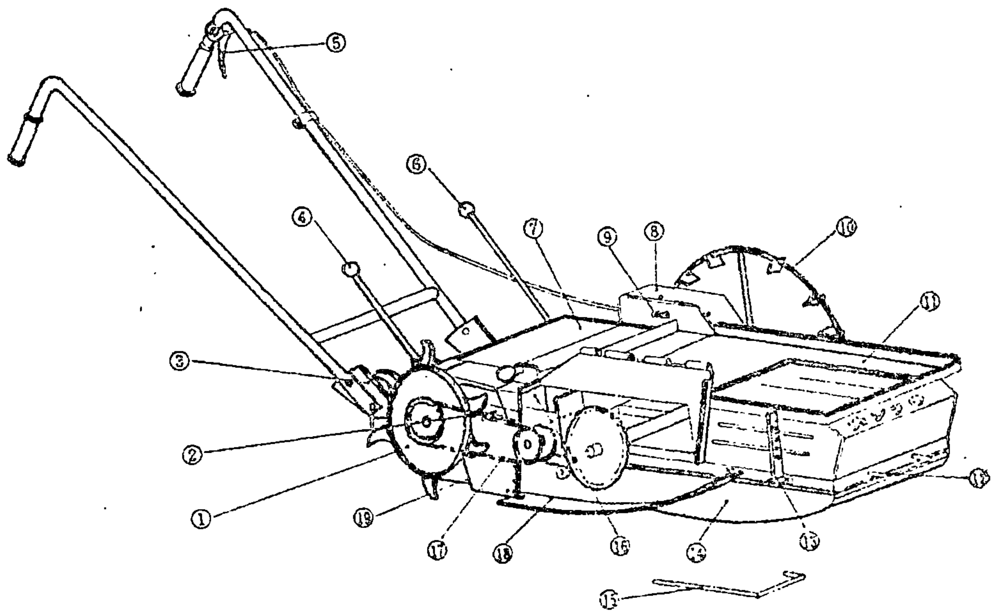


Pot-type nursery box.



Band-type nursery box.

FIG. 2.19 SEEDLING BOXES FOR UNCONVENTIONAL NURSERIES (Fujii,1969)



① Star wheel : to cut and plant seedlings
② Conveyor belt : to carry seedlings
③ Handle-bar controller : to adjust the angle of handle-bar to the machine body
④ Float controller for vertical direction
⑤ Seedlings flow control lever : to control seedlings flowing out from the seedlingbox
⑥ Wheel adjuster : to adjust sinking of the wheels so as to run machine smoothly
⑦ Seedlings guiding board
⑧ Device for carrying out seedlings
⑨ Fixer of roller
⑩ Wheel : to drive other rotating parts
⑪ Seedling box holder
⑫ Handle-bar
⑬ Marker(1) : to adjust the spacing between rows on which seedlings are planted. (Holes from bottom upward on the guide board show those of marker respectively for the spacings of 24, 27, 30, 33, and 36 cm
⑭ Float
⑮ Marker(2) : to be fixed to Marker(1)
⑯ Gear-box
⑰ Chain
⑱ Levelling board : to level the surface of field where rice seedlings are to be transplanted.
⑲ Blade

FIG. 2.20 TRANSPLANTING MACHINE FOR SOIL BEARING SEEDLING (Miura, 1966) performance of the machines (31). The seeding rate depended on the age of seedlings required. Thus, for fourth leaf stage, the rate was 4 grains/1.5 sq.m and for fifth leaf stage it was 4 grains/1.7 sq.cm. Higher seeding density stopped the leaf elongation soon after the three-leaf stage (1). Similarly, a lower density resulted in more missings (31). Substitutes for bed soil, like rice hull, paper pulp and sludges, crushed rice straw, processed cattle excretion, plastic powder and some soil mix, were tried and found to be satisfactory, though the missing and floating of seedlings were more than natural soil (53). Bed soils of over 40 varieties were reported to be commercially available in Japan (18). Raising the seedlings consisted of preparing and treating the bed soil with chemicals, disinfectants and fertilizers, seeding with selected and disinfected seed, pregerminated to about 1.00 mm at the rate of 200 to 250 gm/box, and caring like supply of ample water, and incubation at 30°C for 2 to 3 days. At the 2 to 3 leaf stage after 15 to 25 days of sowing, the seedlings would be of 8 to 12 cm height and ready to transplant (15). Around 100 to 150 nursery boxes were needed/ha.

Miura (46) reported that the transplanters for non-washed seedlings appeared in Japan in 1966, for the first time (Fig. 2.20). Though transplanters using seedlings 5 to 6 leaf stage were introduced, those using young seedlings of 2 to 3 leaf stage were more popular, as these seedlings had less soil thickness. Seedling bands of about 7 mm width were pulled out from seedling holder and cut to about 1 cm by a blade and star wheel. The claw then planted them by pushing into soil.

The machine performed satisfactorily only when (i) seedling belt had no gap more than 1 cm, (ii) roots were well developed and held an optimum amount of soil among themselves, (iii) the soil was not too wet at the time of transplanting, (iv) the soil surface was compact and rather hard, 2 to 3 days after puddling, (v) it was level and even (vi) water level was 2 to 3 cm only. Any break in the seedling belt resulted in more missing and when the soil clod was too wet it stuck to the sheet below and hindered the smooth movement. When the field was too soft the float was sinking and made it hard to drive, whereas, when the field was not level and even, the seedlings submerged in the lower part. Under ideal conditions, the machine transplanted to a depth of 2 to 3 cm at a rate of 1 ha in 30 hrs, with missing hills of less than 10 per cent, but this could not be used for late transplanting.

Another transplanting machine reported to be operated with a power tiller, used continuous band-type seedings. It was a 4-row machine weighing 50 kg and had 30 cm row spacing and adjustable hill to hill distance from 9 to 18 cm by changing the belt pulley. It took 10 to 15 hrs/ha and missing percentage of hills was 1.6 to 8.2 (38).

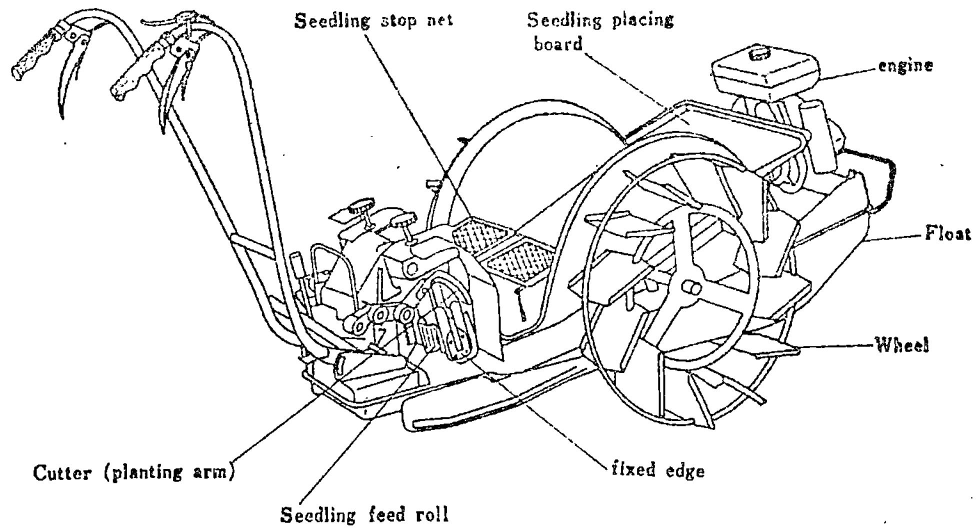


FIG. 2.21 TRANSPLANTING MACHINE WITH FLOAT (Hoshino, 1969)

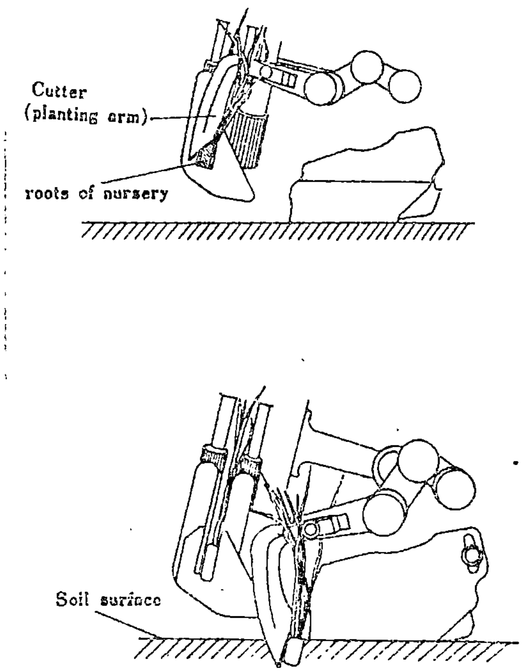


FIG. 2.22 CUTTING AND PLANTING OF BAND TYPE NURSERY (Hoshino, 1969)

As an improvement to avoid sinking and to achieve better manoeuvrability, floats were provided to support the weight of the machine partially. Out of the various materials tried, like fibre glass, plastics, polythylene and steel plate, the latter two were reported to be most suitable for floats due to their lower abrasion resistance (23).

In a 2-row self propelled machine fitted with a float (Fig. 2.21), using continuous band-type seedlings, the end of the band was carried to the fixed edge of the roll. Here, a cutter sliced the band into blocks which were then planted into the field. A seedling stop-net controlled the movement of the seedlings on the seedling placing board through pushing the leaf-tips of the seedlings. It also helped the seedlings to move into the planting system regularly. The height of the net was adjustable to suit the seedling height. Fig. 2.22 shows the slicing and planting operations (19).

As the labour required and expenditure incurred in raising mat-type nursery were less than other types, transplanters for this type of nursery were introduced in seventies (21). These were most popular in Japan and were reported to be manufactured as many as 16 manufacturers (10). A typical machine (Fig. 2.23) had provision to carry enough extra seedling mats

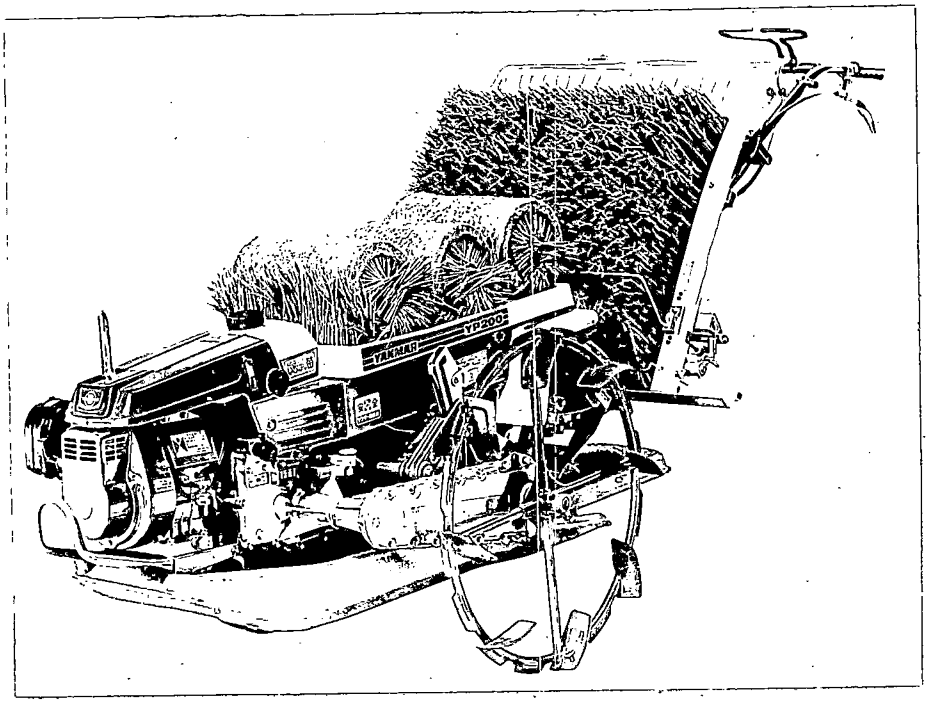
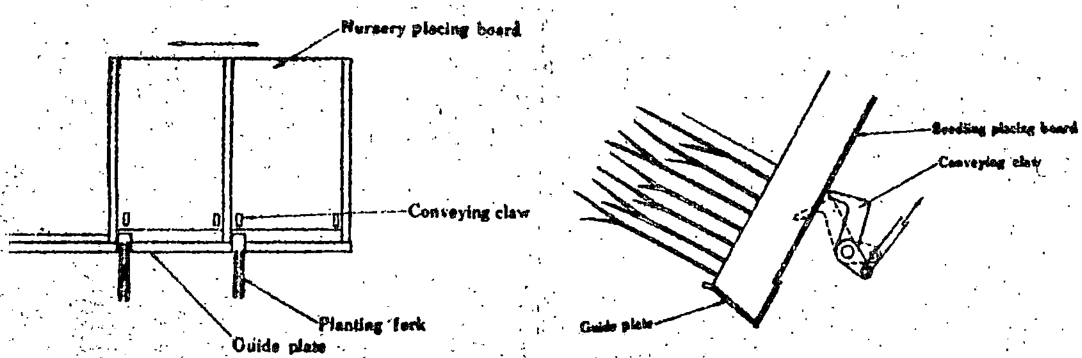


FIG. 2.23 A SELF-PROPELLED TRANSPLANTING MACHINE FOR MAT TYPE NURSERY (Yanmar Agric. Equip. Co., Japan,1979)



Operating process of seedling placing board

Longitudinal sending system of seedlings

FIG. 2.24 MOVEMENT OF THE SEEDLING-PLACING BOARD(Hoshino,1974) and was self-propelled (82). Though there were minor variations between different models, the underlying principle remained the same for all. The seedling placing board moved side ways along a guide plate which had slits at fixed intervals through which the planting fork could separate small blocks of seedlings to be transplanted as shown in Fig. 2.24. As the nursery placing board reached one end, a lower layer of seedlings was removed, the mat was pushed longitudinally downward by a conveying claw and then the board reversed its direction along the guide plate. Different arrangements of the planting forks to cut and release the seedlings could be seen on transplanters made by different manufacturers, but all of them worked by a link mechanism driven by a crank arm mounted on a shaft that was powered by an engine as shown in Fig. 2.25. In one arrangement the forks got displaced with respect to each other to release the seedlings. Fig. 2.25 shows this type. In another type the planting fork rotated through certain angle to widen the gap between them and thereby release the seedlings, while a third arrangement employed a supplementary fork to push out the seedlings from the claw of the planting fork. Fig. 2.26 illustrates these. These machines were reported to be highly reliable, accurate and most popular. Out of 13 models of transplanters that had undergone national test in Japan in 1975, 11 were of this type (47). The important technical specifications of these were given in Table2.1.

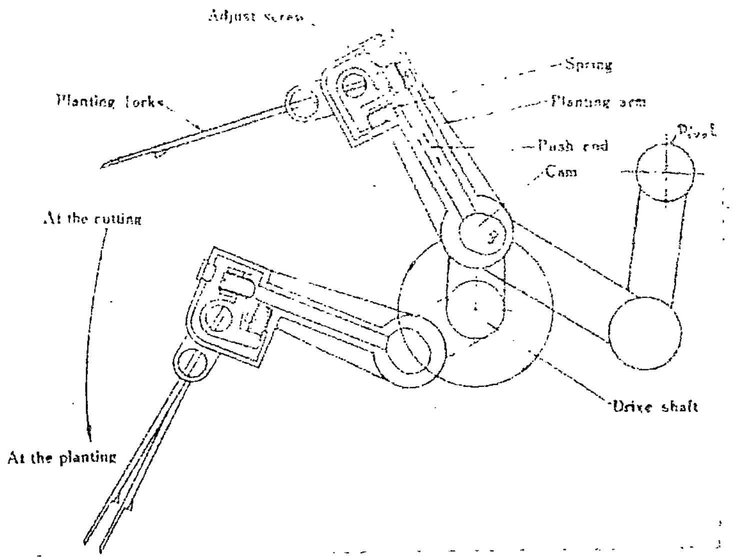


FIG. 2.25 LINK MECHANISM OF THE PLANTING FORK FOR MAT TYPE NURSERY (Hoshino, 1974)

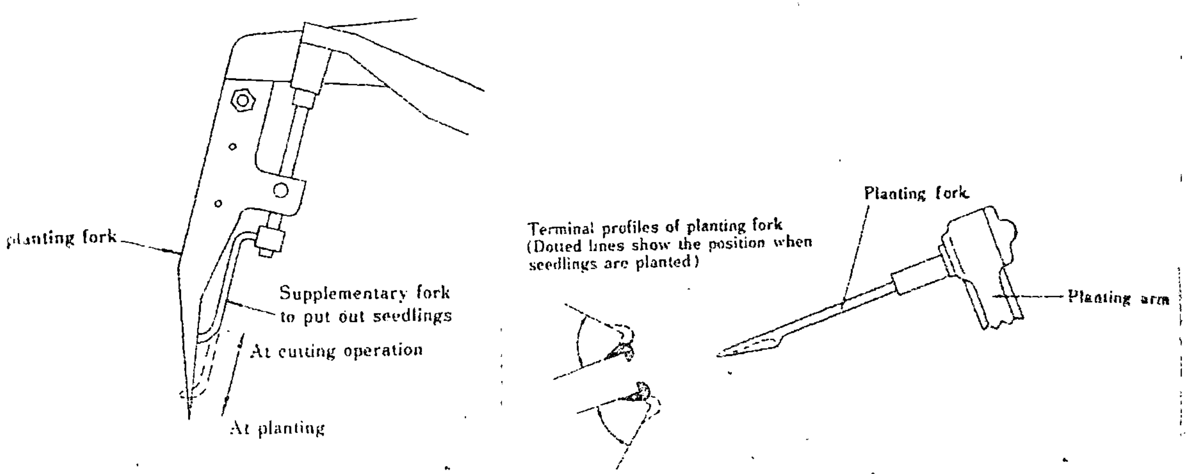


FIG. 2.26 TYPES OF PLANTING FORKS FOR MAT TYPE NURSERY (Hoshino, 1974)

Table 2.1 Specifications of transplanters tested in Japan in 1975(47)

Sr. No.	Description	2-row	4-row
1	2	3	4
1.	Weight (including seedling mat) (kg)	89-107	154-179
2.	Power (engine with recoil starting) (hp)	1.6-2.5	2 - 2.5
3.	Inclination of seedling placing board (made of aluminium or plastic) (degree)	50-60	50-60
4.	Row spacing (not adjustable) (cm)	28,30 31 & 33	28, 30 31 & 33
5.	Hill to hill distance (adjustable at 2 to 4 levels) (cm)	11-20	11-20
6.	Plant hill density (Theoretical-hills/sq.m.)	16.3-27.9	16.3-27.9
7.	Depth of planting (adjustable to 3-4 levels) (cm)	2-4	2-4
8.	Capacity (ha/hr)	0.114	0.160
9.	Forward speed (kmph)	2.27	1.76
10.	Plant hill missing (%)	2	2

These machines were reported to be quite popular in Japan. Many problems such as difficulty in seedling raising, withering after transplanting, excessive tillering, comparatively higher costs of materials for seedling raising and higher cost of machines were still being solved (68).

Singh and Garg (69, 70) reported the development of a ten-row tractor-mounted paddy transplanter using mat-type seedlings, in the Department of Farm Power & Machinery, PAU, Ludhiana (Fig. 2.27). It planted seedlings at a row spacing of 26.6 cm and hill to hill distance of 14 cm. The test results showed a capacity of 0.18 ha/hr at a working speed of 1.24 kmph with plant hill missing of 12 per cent (58). It required 28 man-hrs/ha for driving the tractor and feeding the seedlings. The development was still in progress.

A simple transplanter for mat-type of seedlings was reported to have been designed at I.R.R.I. which had three sets of pickers mounted on a shaft driven by a ground wheel though chains (Fig. 2.28). A guide was provided to prevent the seedlings from dropping off the picker as they were pulled from the tray. A crank driven push rod planted the seedlings. Test results showed plant hill missing of 5 to 37 per cent (28, 30, 44).

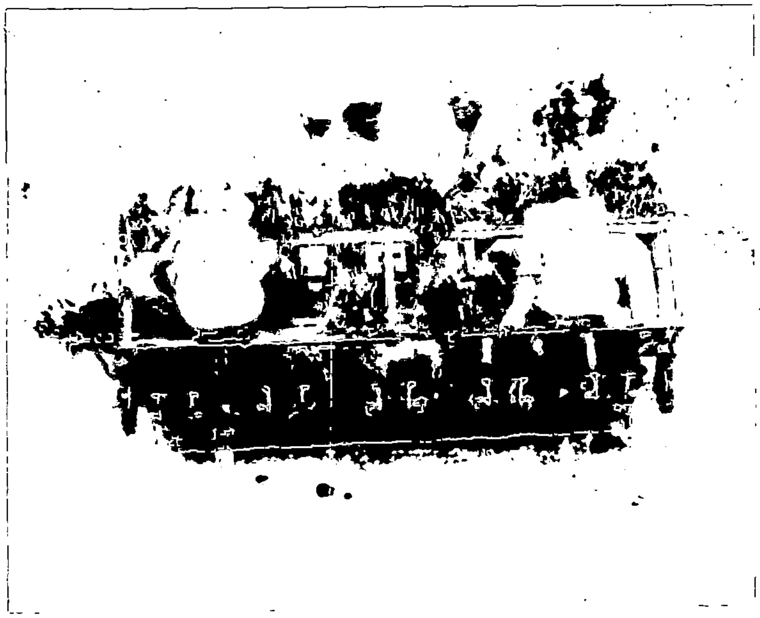


FIG. 2.27 TRACTOR-MOUNTED PADDY TRANSPLANTER (Singh and Garg,1976)

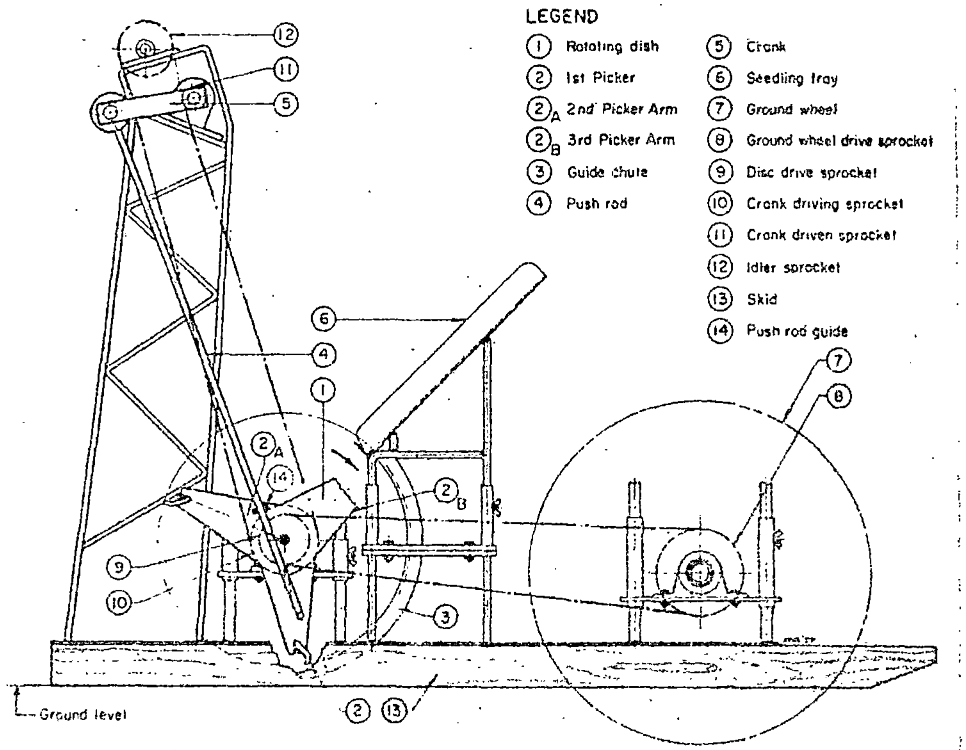


FIG. 2.28 GROUND-WHEEL DRIVEN TRANSPLANTER (IRRI, 1976)

A tractor-mounted transplanter for mat type seedlings had been developed under a co-operative project between Malaysia and Japan (63). After modifying the initial modesl named 'Tanima' and 'Ganti', the latest 8-row version 'Handai' (Fig. 2.29) mounted on to a half-track tractor was reported to have hill missings of 10 per cent as against 42 per cent in the initial models (63). It was reported to be capable of operating in 10 cm deep standing water at a speed of 0.3 m/sec. Its capacity was about 0.24 ha/hr.

A simple 4-row manual transplanter for soil bearing seedlings had been developed at I.R.R.I. (63). It used three-point non-grasping pickers. The downward stroke of the handle picked and planted the seedlings and the upward stroke released them (Fig. 2.30). A tray drive pawl and ratchet mechanism along with a feeding frame were used to ensure positive feeding of seedlings. Field tests and evaluation were in progress (63).

2.1.3 Some innovative approaches for paddy transplanting

The foregoing dealt with the transplanting aids and machines, where the process was entirely mechanical and was aimed at replacing the human fingers with mechanical fingers. Because of the numerous difficulties encountered in this

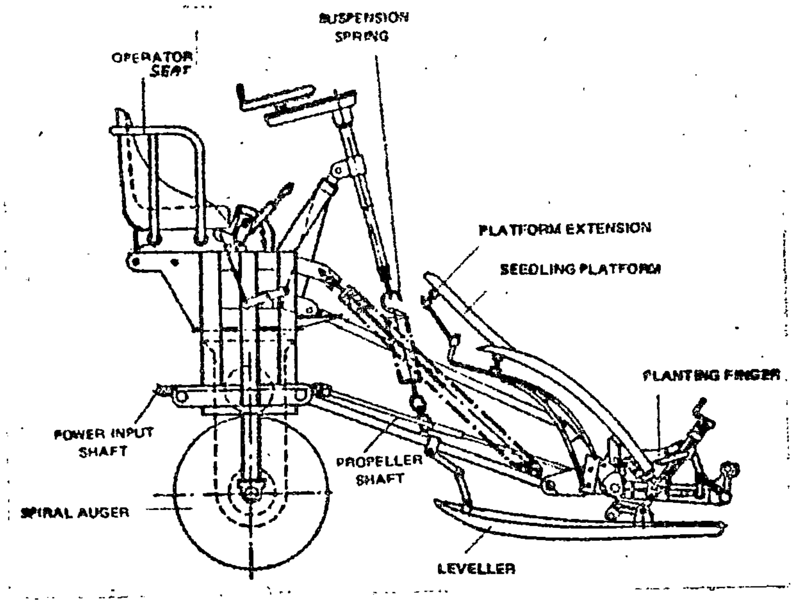


FIG. 2.29 'HANDAI' TRACTOR-MOUNTED TRANSPLANTER (RNAM, 1979)

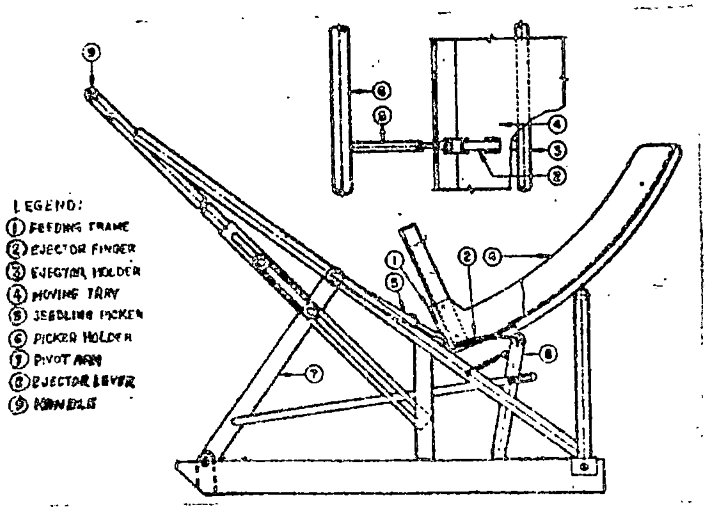


FIG. 2.30 THE IRRI-MANUAL TRANSPLANTER FOR MAT-TYPE SEEDLINGS (RNAM, 1979)

process, some entirely new approaches had been reported which are being briefly reviewed.

A gravity-type hand operated transplanting equipment was developed and tested in 1955 in Taiwan (13). It planted the seedlings with small mud-balls attached to their roots. As the device was drawn forward the mud-balled seedlings were dropped through a tube from a height of about 122 cm. The kinetic energy acquired during the fall and the parachuting action of the leaves planted the seedlings quite erect, to the required depth. The excessive labour requirement for making the mud-balls at the roots of individual hills forbade this concept from popular use.

Huang and Splinter (22) reported the development of an automatic transplanter in 1968, which was meant for transplanting the seedlings of tomato, tobacco, cabbage etc. under the dry field conditions. The machine consisted of (i) a grid cartridge-carrying and feeding unit for seedlings, (ii) a drop and suction device and (iii) furrow openers and press wheels. The first unit had a group of rectangular cartridges of 60 cm x 120 cm size, which held potted seedlings in rows. The bottom most cartridge was fed into a conveying mechanism which had a fixed bottom plate with a box. As the cartridge moved over the bottom plate, the seedling-pot could be dropped through the hole, when the pot coincoded with the hole. The drop tube was fitted with a suction device connected to a p.t.o. driven blower, which created a thrust of 0.68 kg at full speed. This was inevitable at high forward speed for perfect planting. The opener was a specially designed shovel with side and centre spikes to pulverise the soil in furrow so as to absorb the impact of falling of the seedling pots. The press wheels set at the angle of 45^{o} to the ground closed the furrow around the transplants without excessive compaction. The major disadvantage reported was preparing of the potted seedlings requiring higher labour and expenditure. Similar machines were also tried for dry field by other researchers (75, 81).

A tractor-mounted manual metering type, 7-row paddy transplanter was developed and tested at Tractor Training and Testing Station, Budni (71,79). This consisted of seven tubes, each of 100 cm length, mounted on a frame. Seedlings kept in a container were separated into small hills and dropped through the tubes manually. These were planted due to gravity. It was found that some seedlings were buried owing to the flow of soil due to wheel movement. This led to improper planting as the seedlings were not carrying sufficient mud to impart enough momentum for proper anchoring.

In the northern parts of Japan, use of mat-type nursery with young seedlings resulted in delayed tillering and were prone to cool weather damage (32). This led to the transplanting of paper-potted seedlings of 30 to 35 days age by broad casting. Manufactured by several firms, paper-pots are bottomless containers of 1.5 cm x 1.5 cm size with 3 cm height (50). These were arranged on blocks each containing 760 pots in 38 rows of 20 pots. 350 blocks/ha were needed. Lately, 12600 pots of 1.9 cm diameter were tried on a single block as shown in Fig. 2.31. These were filled with loam or clay loam soils at a rate of 1800 kg/ha, using vibrating table manually or by power soil-packing and seeding machines as shown in Fig. 2.32. These required 21 and 10 to 14 man-hrs/ha respectively. After proper caring for 30-35 days, the seedling hills were separated by holding the plants of about 20 pots by hand and gently beating the soil, requiring 6 to 7 man-hrs/ha. The separated seedlings were carried in suitable containers and transplanted by hand broad casting about 10 to 15 hills at a time, requiring 10 to 12 man-hrs/ha as shown in Fig. 2.33. A height of fall of 2 m was found to be adequate for proper planting of a hill weighing 6 to 7 gm. This method was also practised by riding on a platform or trailer attached to a tractor. Semi and fully automatic drill planters were also reported to be in use, in which seedling hills were dropped

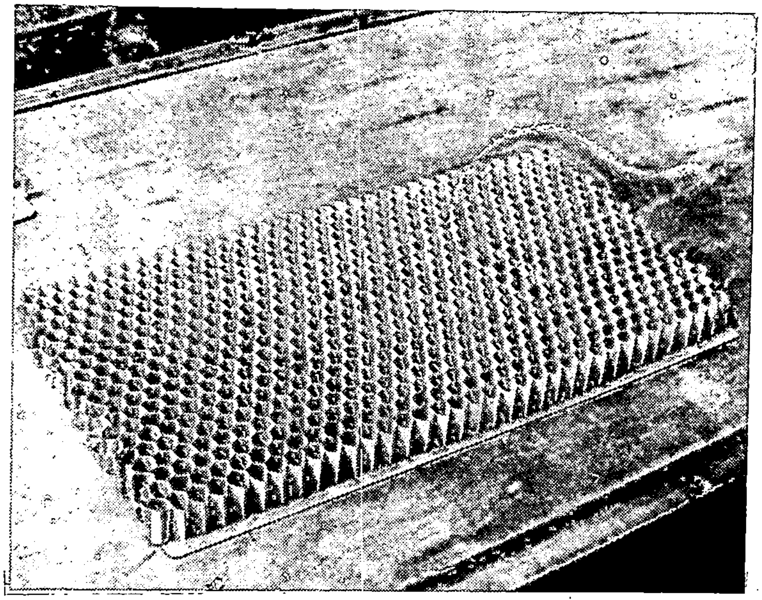


FIG. 2.31 Paper pots for paddy seedlings (Kawasaki, 1976)

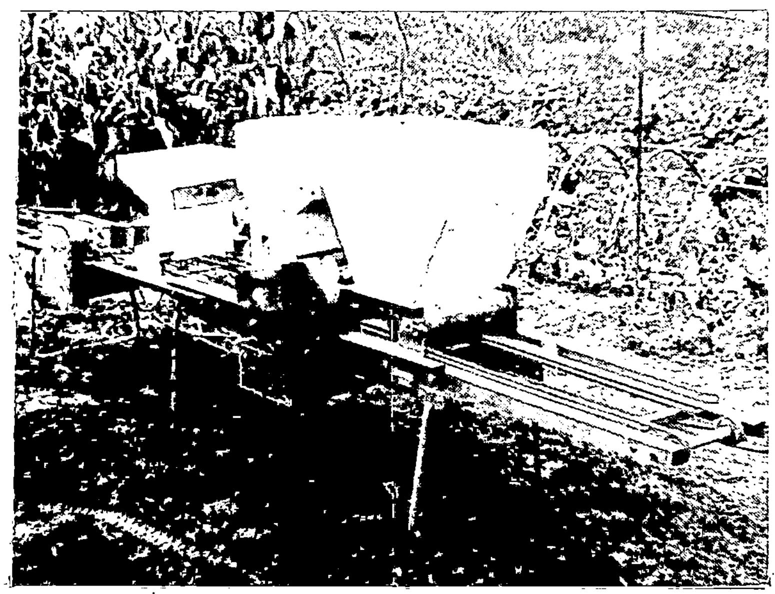


FIG. 2.32 Soil stuffing and seeding machine for paper-pot seedlings (Kawasaki, 1976)

FIG. 2.33 Hand-broad casting of paper-pot seedlings (Kawasaki, 1976)

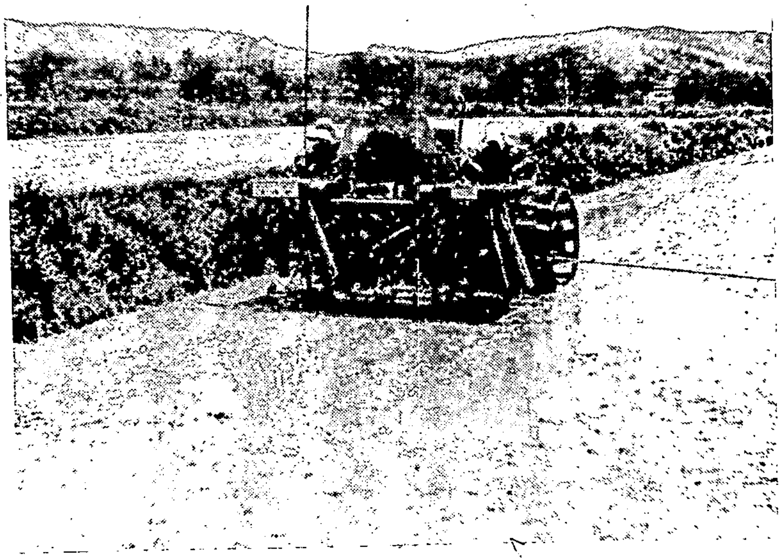


FIG. 2.34 Semi-automatic planter for paper-pot seedlings (Kawasaki, 1976)

from a certain height through a chute to plant them in rows. A 12-row drill planter with 6 workers required about 20 man-hrs/ha Fig. 2.34 shows this planter. Paper-pot transplanting had the disadvantage that seedlings sometimes remained lying on the soil surface or got buried in the soil. Further, it required more labour for soil filling and separation of pots, thinning or supplementing when hand broadcast, and correct water level in the field.

Kawashima and Tanabe (33) reported that the growth of paper pot seedlings was accelerated in nursery bed and was vigorous during the initial stage of field growth. As the direction of root growth was regulated by the pots, the distribution of the roots concentrated near the surface of field. The growth was depressed after the terminal period of vegetative growth with a reduction in total dry matter and grain yield. Forty day old seedlings were reported to be better than 20 day old seedlings regarding yield.

Ching and Cuang (7) studied a model seedling tube for use in gravity-type rice transplanter. They reported that the suctional force created due to fall was proportional to the bed soil moisture content. When a seedling of 3 gm weight was dropped from 58 cm height an impulsive force of 348 gm was found to act but this was insufficient to plant the seedling when the bed soil moisture content was 20 per cent. However, when moisture content increased to 30 per cent, the seedlings could adhere to the soil surface (7).

Singh (72) reported the results of another approach for transplanting ordinary rice seedlings by pneumatic injection into wet soil. The concept was to make a furrow in the puddled soil by an air jet of sufficient velocity coming from a tube and then drop the seedling hill through this tube so that these would get planted in the furrow already made. However, investigations showed that this concept could not be put in the development of a rice transplanter, because, the maximum relative velocity of 16 m/sec that produced a drag force of 2.1 gm on a typical seedling without any stem damage could make only a depth of penetration less than 5 mm, against the required depth of 3 cm. He concluded that either a mechanical opener with a seedling tube system or a double tube system in which one tube with high velocity air-stream for furrow making and the other with low velocity air-stream for seedling injection could be feasible. A similar approach using a jel-base fluid to inject the seedlings was reported to be in progress (52).

Tape- transplanting was also reported to have been tried for paddy transplanting (8, 13). In this process, jute strings were pasted on a base paper placed on a seedling tray. Water-soaked seeds were spread over the stringed paper using a spacer grid. After sprinkling some water, the trays were kept one above the other for 24 hours and after germination of the seeds these trays were kept open and water was applied frequently. Seedlings, after 11 to 15 days, got attached to the strings by their roots. For transplanting, the string carrying the seedlings was stretched across the puddled field and dipped in the loose soil to the required depth. Thus the seedlings were planted into the soil. Though the correct economics was not known, it was claimed to be more economical than hand-transplanting (8).

2.2 Agronomic Aspects of Paddy Transplanting

Paddy was a highly adaptable crop that was grown under a variety of agricultural, climatic and soil conditions. Availability of water was its primary need (24). Owing to various advantages, transplanting was the more widely accepted method than direct seedling with ordinary or pregerminated seeds. Regarding the yield, research findings were for and against the transplanting. Many experiments had shown an increase in the yield by as much as 30 per cent, while many other experiments showed that direct seeding could give up to 26 per cent more yield than transplanted crop (6,27,41,61,62). In some other cases both the methods were reported to have comparable results (6,60). Scientists had, therefore, concluded that there were no fundamental differences in yield if good management was practised in each method (27). But transplanting enabled easy management, saving in time, water, weed and pest control expenditure and the maximum use of land.

Saini (64) reported that a maximum yield upto 10,674 kg/ha was obtained by line transplanting while the average yield by random transplanting was only 3700 kg/ha. He attributed this increase to several reasons such as optimum stand of crop, uniform distance between hills, more interception of solar vadiation, easy and effective weeding with rotary weeders, easy intercultural operations etc. This also helped to provide oxygen to the roots, stimulated micro organism, mixed fertiliser thoroughly, facilitated top dressing of fertiliser, provided immunity against diseases and insects, allowed effective spraying, and protection against wind and storm (64). Patel and Kumar (56) as well as Reddi (62) also reported 6.02 and 2.4 to 8.35 per cent increase in yield by line transplanting. Japan enacted alaw so that farmers were forced to transplant paddy in line and consequently could double the production in 2 to 3 years (64).

Regarding some allied aspects like optimum spacing of hills, depth of transplanting, age of seedlings, and time of transplanting, the research findings and consequent suggestions and recommendations were not consistent. Table 2.2 summarises the findings of various scientists in India and abroad relating to these aspects.

Table 2.2 Agronomic recommendations for paddy transplanting

Sr. No.	Description	Recommendation	Recommended by
1	2	3	4
1.	Spacing	22.5cm x 22.5cm (Tall variety)	Mahapatra et al (41)
		22.5 cm x 15cm (Medium)	
		15cm x 15cm (Short)	
		25cm x 25cm (Tall); 30cm x 15cm (Tall lodging variety); 25cm x 25cm (Medium)	Bhan (4)
		20cm x 20cm (Short)	
		15cm x 25cm (Medium)	Paul and Mitra (57)
		10cm x 10cm(Short, and increase according to duration)	Panda and Leeuwrik (54)
		30cm x 30cm (Tall in poor soil, wet season)	
		25cm x 25cm (Medium in poor soil, wet season)	I.R.R.I. (27)
		20cm x 20cm (Short in poor soil, wet season)	
		35cm x 35cm (Tall in fertile soil, wet season)	

Table 2.2 contd...

1	2	3	4
		25cm x 25cm (Tall in poor soil, dry season) 30cm x 30cm (Tall in fertile soil, dry season)	
		20cm x 15cm (Kharif) 20cm x 10cm (Rabi)	I.C.A.R. (25)
		20cm x 15cm (Normal) 15cm x 15cm (Late)	P.A.U. (59)
		20 x 20cm (Tall); 20 x 15(Medium); 15 x 15 (Short)	F.A.I. (11)
		20cm x 15cm (Medium) } Ist crop 15cm x 10cm (Short) } 20cm x 10cm (Medium) } 2nd crop & 3rd crop 15cm x 10cm (Short) }	K.A.U. (34)

Table 2.2 contd...

1	2	3	4
2.	Age of seedlings (days)	28 to 35 (Tall) 21 to 28(Short) 30(Short duration variety)	Mahapatra et al (41) Sanchezard Larreat (65
		35 to 38 (Tall) 24 to 28(Medium) 21 to 24 (Short)	Haveten (17)
		21 (Short and increase according to duration)	I.C.A.R. (25)
		21 to 28(Medium and change according to duration)	I.R.R.I. (27)
		25 to 42 for 120 to 180 days of duration	F.A.I. (11)
		30 (Short) 25 - 35 (Tall)	P.A.U. (59)
		40(Tall) 20 to 25 (Medium-2nd & 3rd crop) 18 days(Short-2nd & 3rd crop) 25 (Short-Ist crop) 35 (Medium-Ist crop)	K.A.U. (34)
3.	Time of transplanting	June 25 to July 10 (Punjab)	Sood and Singh (74)
		Late July to August (Orissa)	Mahapatra et al (41)
		June 30 to July 15 (Bareilly)	Singh et al (73)
		June to July(Short) Mid July to August (Tall)	P.A.U. (59)
		April-May (Ist crop) Sept-Oct. (II crop) Dec.-January (III crop)	K.A.U. (34)

Table 2.2 contd...

1	2	3	4
4.	Depth of Transplanting (cm)	2.5	F.A.I. (11)
		2 to 3	P.A.U. (59)
		3 to 4	Haveten(17); K.A.U.(34)
		3 to 4	Nair et al (48)
5.	Number of seedlings/hill	2 to 3	P.A.U. (59); K.A.U.(34); Mahapatra et al (41); I.R.R.I. (27);F.A.I. (1
		6	Bhan (4)

Chapter III

MATERIALS AND METHODS

This chapter deals with the design details, modifications incorporated during the course of development and testing procedures used for a new type of paddy transplanting mechanism developed for this study. It is arranged under the following titles:

1. Design considerations and development of the transplanting mechanism
2. Test set-up and procedures used

A critical review of the merits and demerits and the difficulties encountered in the performance of the transplanting mechanisms already developed for conventional seedlings revealed the following facts:

(a) The time required for washing, pruning and separating the seedlings was considerably high which reduced the economy of machine transplanting (70, 79)

(b) The reciprocating or oscillating type of picker assembly had limited operating speed and hence less capacity (13, 70)

(c) The positive conveying of seedlings to the pickers was difficult and this resulted in higher missing hills (66)

(d) The roots were entangled and in most cases seedlings more than required were pulled and scattered on the field (13, 66)

(e) When the same fingers were used for picking and planting, seedlings often struck to the fingers due to their passing through the mud and were not properly released (70, 79)

(f) The mechanisms were either power or manually operated but were not versatile enough to be operated by human, animal or mechanical power.

It was, therefore, decided to design a paddy transplanting mechanism suitable for conventional washed-root seedlings to overcome the aforementioned drawbacks as far as possible.

3.1 Design Considerations and Development of the Transplanting Mechanism

Based upon the agronomic aspects of rice transplanting reviewed under section of 2.2 of Chapter II, and with a view to overcome the shortcomings of the earlier designs enlisted above, the mechanism was designed to satisfy the following requirements:

1. It should transplant seedlings with a hill to hill distance of 15 cm and row to row distance of 20 cm
2. The number of seedlings per hill should be two to three
3. It should be able to transplant seedlings with missing plant hills not exceeding 5 per cent
4. It should not cause seedling damage more than 1 per cent
5. The depth of transplanting should be between 3 and 4 cm
6. The seedlings should be transplanted, as far as possible, erect
7. It should be able to use the seedlings with minimum root-washing and preparation
8. It should be able to use seedlings of a maximum length of 30 cm
9. It should be able to pick out 2 to 3 seedlings from the seedling box without pulling out extra seedlings
10. The seedlings picked from the seedling box should be easily released by the pickers, but be planted by a separate planting finger so as to keep the pickers free of mud.

11. It should be portable, cheap, simple and easy to maintain by an average Indian farmer.

In order to achieve these objectives a transplanting mechanism comprising the following systems was designed, developed and tested:

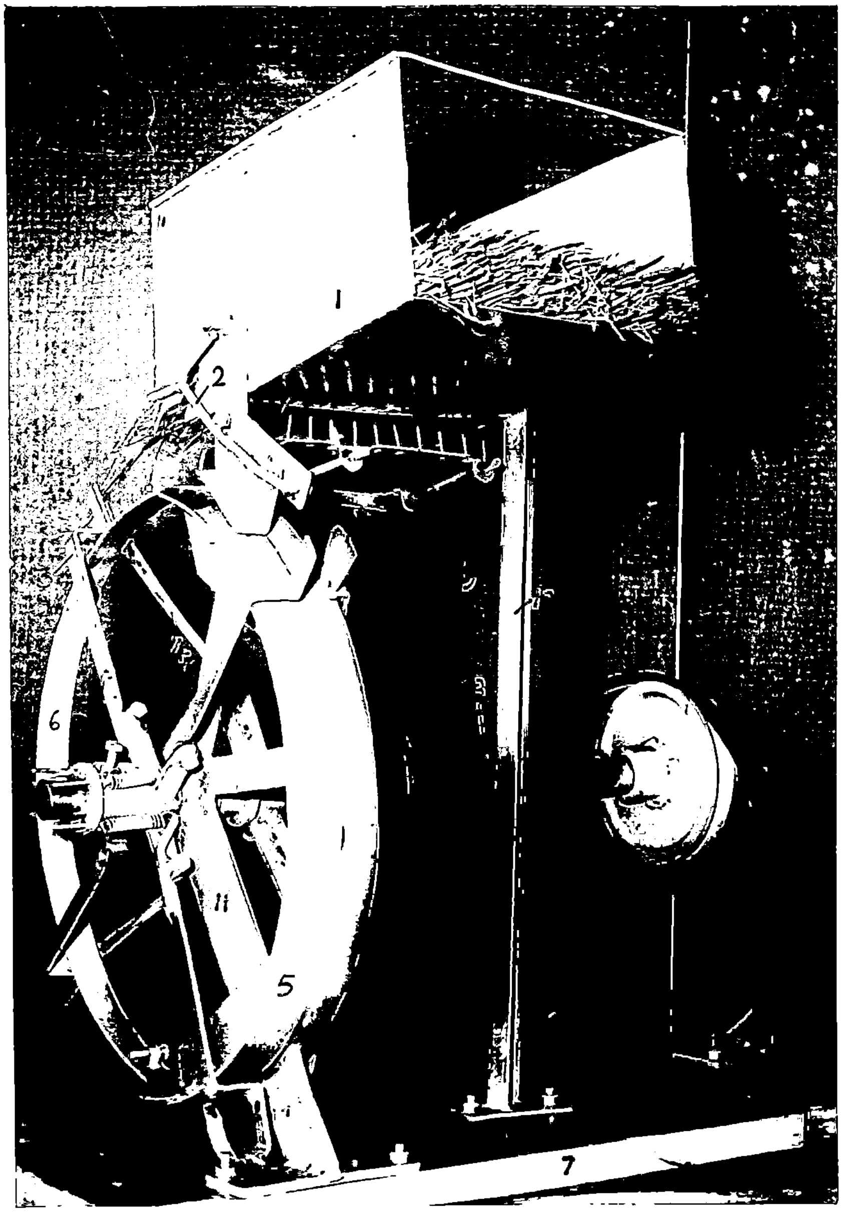
1. Seedling holding and conveying system
2. Seedling picking and releasing system
3. Seedling planting system

Two mechanisms one with two-picker-sets and another with four picker-sets were designed and constructed. The mechanism with two picker-sets will, hereafter, be denoted as mechanism-A, and that with four picker-sets as mechanism-B.

Fig. 3.1 shows the mechanism developed, with the relative positions of various components.

3.1.1 Seedling holding and conveying system

3.1.1.1 Seedling box: It was decided to provide a seedling box of adequate capacity to hold the seedlings to transplant an area of 10 sq.m. A width of 20 cm for the box was chosen such that another similar unit parallel to this with a row to row distance of 20 cm could be conveniently accomodated. The depth of the box at the rear side corresponding to this was



1. Seedling box
2. Seedling ejector
3. Pivoted picker
4. Fixed picker
5. Cam for pickers
6. Stationaery frame
7. Wooden float
8. Main shaft
9. Seedling rake
10. Support-seedling box
11. Main support

FIG. 3.1 Paddy transplanting mechanism-complete view found to be 15.5 cm. Therefore, a seedling box of 30 cm length, 20 cm width and 15.5 cm average depth was fabricated out of plain G.I. sheet of 26 G. The top and front sides were kept open for easy loading of the seedlings. It was mounted such that the seedlings were kept parallel to the direction of travel.

3.1.1.2 Seedling conveying system: The seedlings were to be picked from the box through an opening in the right bottom-corner at the rear end of the box. It was presumed that given a suitable slope to the bottom of the box the seedlings would move towards the opening due to gravity and slight vibrations induced by the mechanism when in motion. By placing the seedlings on an inclined plain G.I. sheet and changing its inclination gradually it was found that a slope of about 38^{o} with the horizontal was adequate to overcome the friction between the sheet and seedlings and to slide the seedlings downward. In the initial design this slope was provided to the bottom of the box. The size of opening at the right bottom corner of the box was 1.5 cm wide, 1.5 cm deep and 4.5 cm long (Fig. 3.2). This was found to be adequate to permit the pickers to grasp 2 to 3 seedlings from the box in each picking. In order to check the proper movement of the seedlings due to the inclination provided to the bottom, seedlings at the rate of 2 to 3 per hill were pulled out by hand.

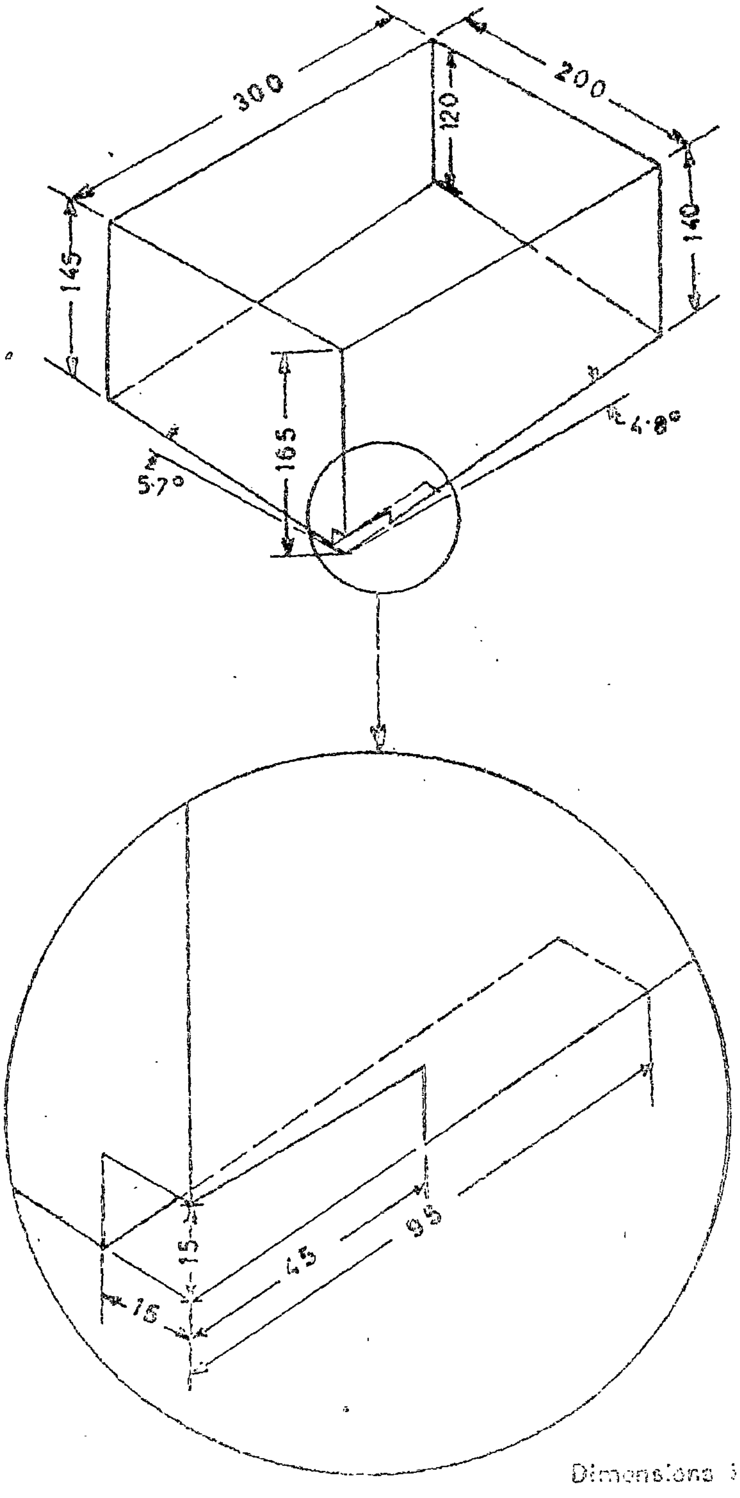


FIG.3.2 DETAILS OF THE SEEDLING BOX AND ITS OPENING

It was found that after taking out 2 to 3 hills, the space at the right bottom corner of the box became void and the slope provided alone could not move the seedlings positively to the opening. A metal sheet with some weight on it was kept over the seedlings in the box to press them down, but this did not lead to any improvement. It was, therefore, concluded that a positive seedling conveying mechanism was inevitable.

An endless leather belt of 1 cm width was provided with its one side running over the bottom of the box, at a distance of 2.5 cm from the rear end and parallel to that. It was carried over a pair of M.S. pulleys of 2 cm diameter mounted at the bottom of the box, along its length. The shaft of one of the pulleys was rotated by hand and seedling hills were removed through the opening. After taking out 2 to 3 hills, the space near the opening remained empty and further picking was not effected indicating that a smooth belt would not serve the purpose. Then, metallic projecting strips of 5 x 7 mm size cut into a tooth like shape, were fixed on the belt at spacings of 2 cm as shown in Fig. 3.3 (a). Seedling hills were pulled out by hand and it was found that as much as 8 hills could be taken out. Thereafter, the seedlings moved in a tilted fashion as the drag by the belt was applied only near the roots. Hence another similar parallel belt was provided at a distance of 8 cm from the first and was driven by pulleys on

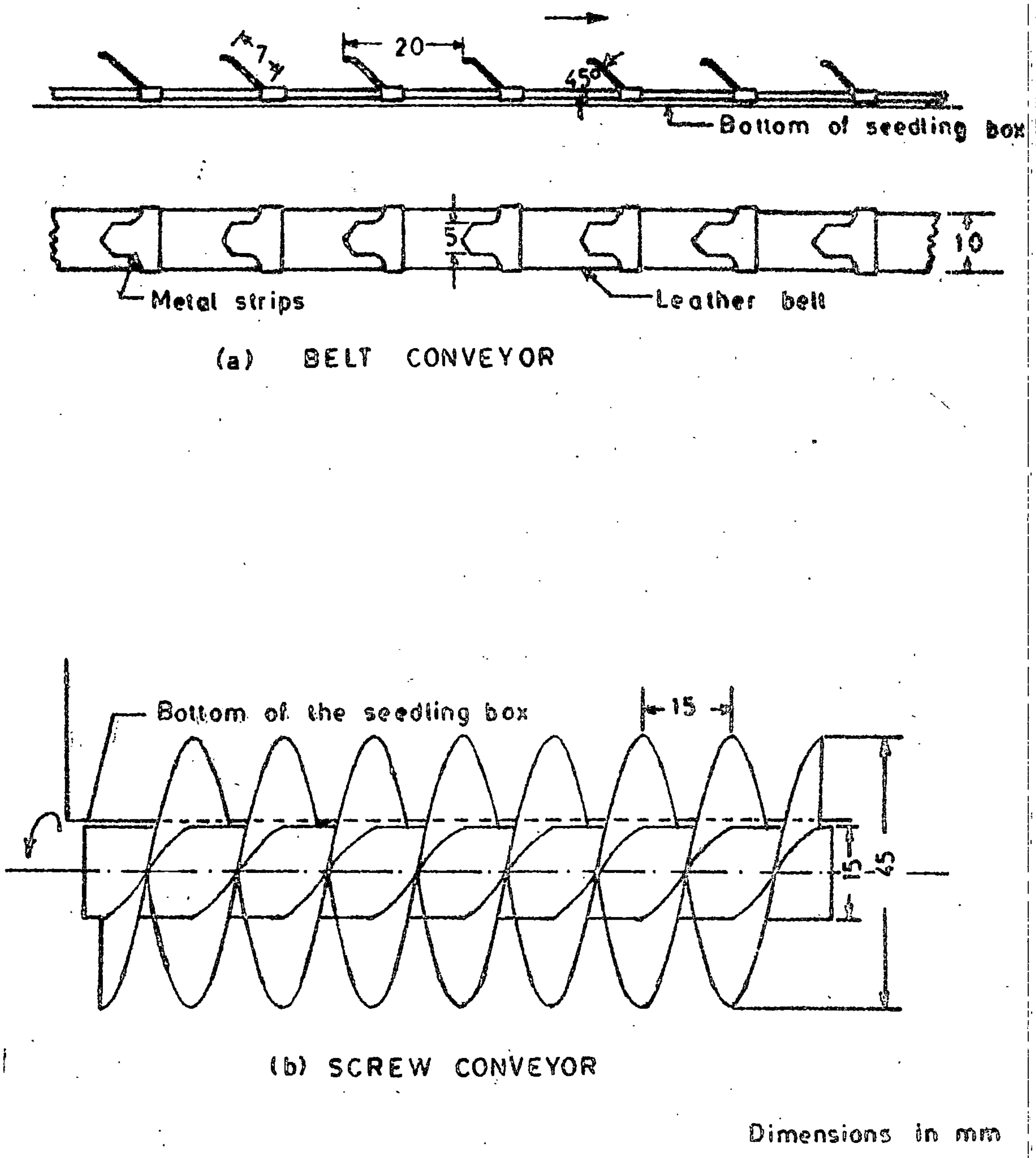
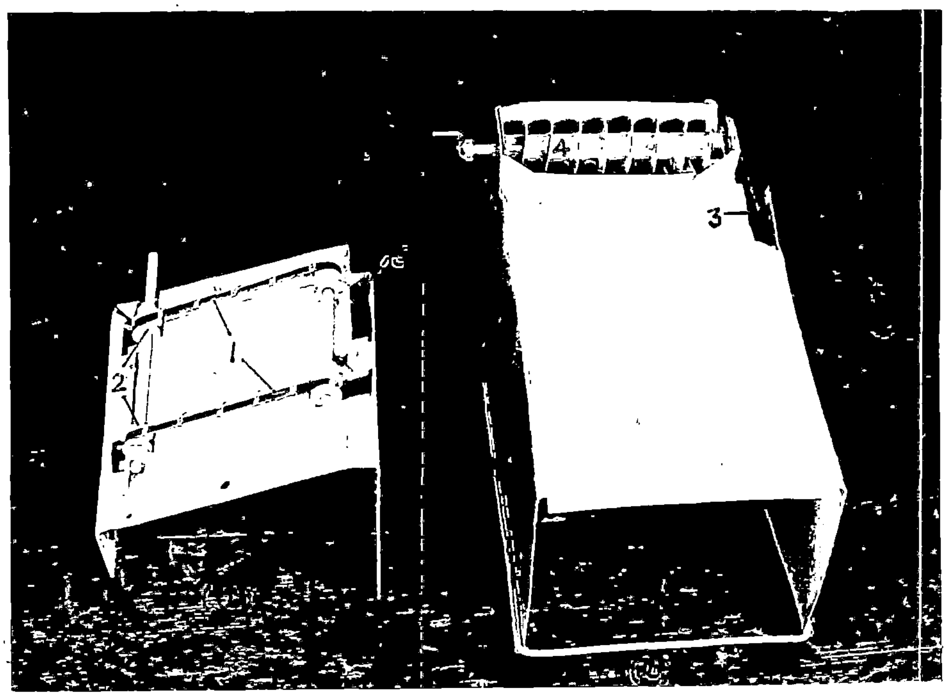


FIG.3.3.DETAILS OF THE BELT AND SCREW CONVEYORS

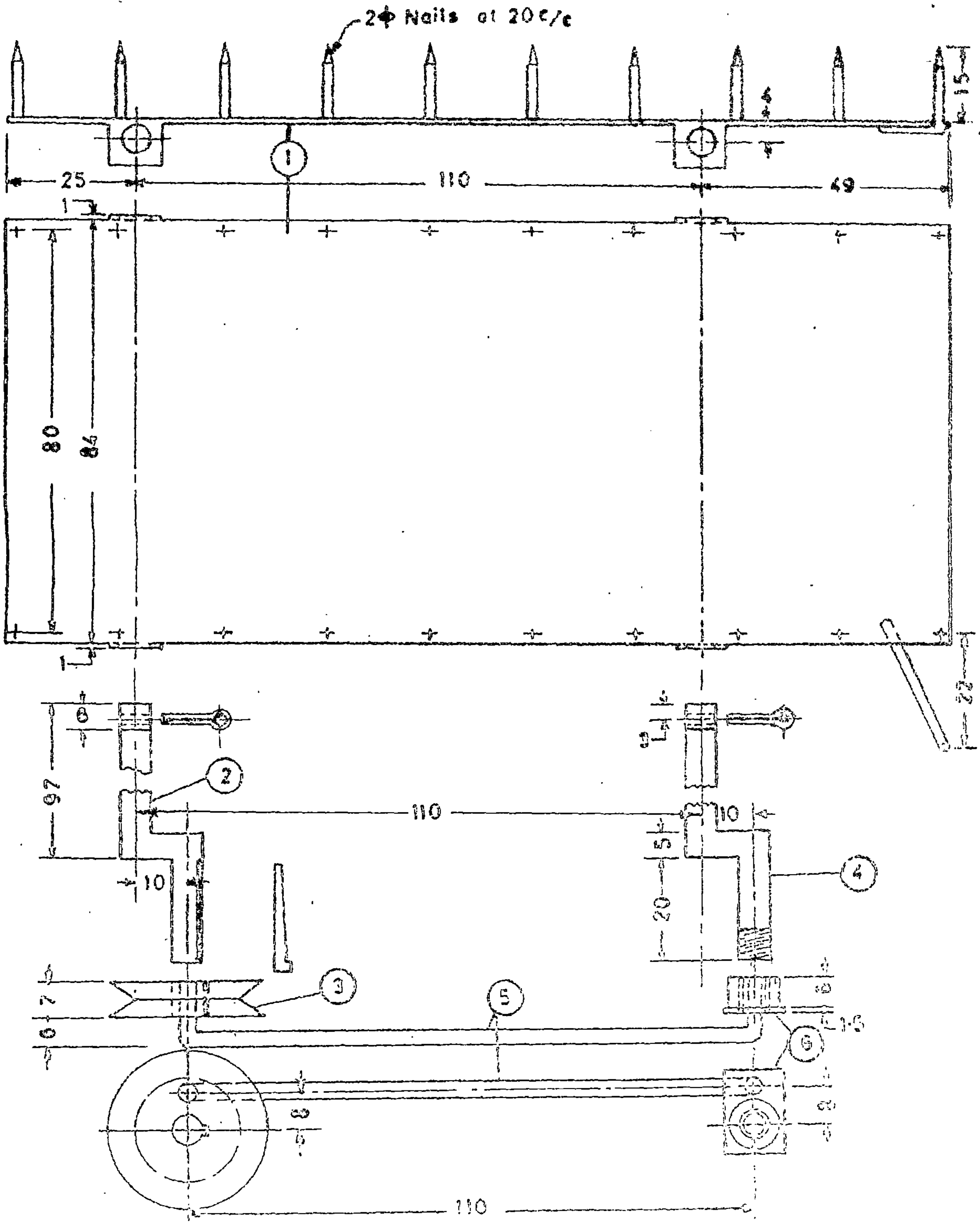
a common shaft with the first set of pulleys, as shown in Fig. 3.4(a). Trials by hand using this showed that this could move the seedlings towards the opening. It, however, presented two major difficulties. Firstly, the metallic projections tended to entangle with the roots and leaves and pulled the seedlings down or they wrapped over the pulley near the opening. Secondly the movement was not regular and consistent and as such the feeding was not uniform, leading to irregular pickings.

A screw conveyor of diameters 4.5 cm and 1.5 cm at outside and inside respectively and a flight pitch of 1.5 cm was tried. Fig. 3.3 (b) shows this conveyor. It was made of G.I. sheet of 28G. Mounted at the rear bottom end of the box it was kept projecting 1.5 cm above the bottom of the box as shown in Fig. 3.4 (b). On trial by hand, it was found that this could move the seedlings positively and regularly, but had one drawback that many a times the seedlings were pulled down at their roots when these got in between the conveyor and the rear side plate of the box. Thus, a better conveying method was considered necessary. Another attempt made to tackle this problem was the use of a seedling rake (Fig. 3.5). Made of M.S. sheet of 14G with M.S. nails of 1.5 cm height, brazed to it in two rows with 8 cm spacing in between at a centre to centre distance of 2 cm, it was driven by a pair



1. Belt conveyor with metal strips
2. Driving pulleys
3. Seedling box opening
4. Screw conveyor

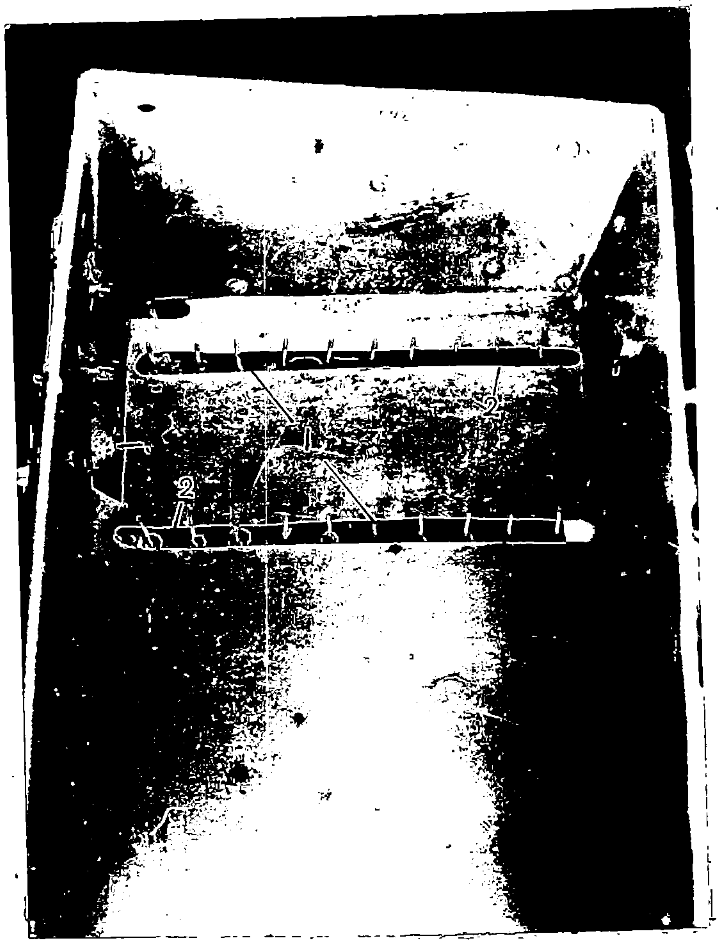
FIG. 3.4 Mounting details of the seedling conveyors



1. Seedling rake 2. Driving crank 3. 25ϕ Pulley for driving crank
4. Driven crank 5 Coupling rod 6. Crank for coupling rod

Dimensions in mm

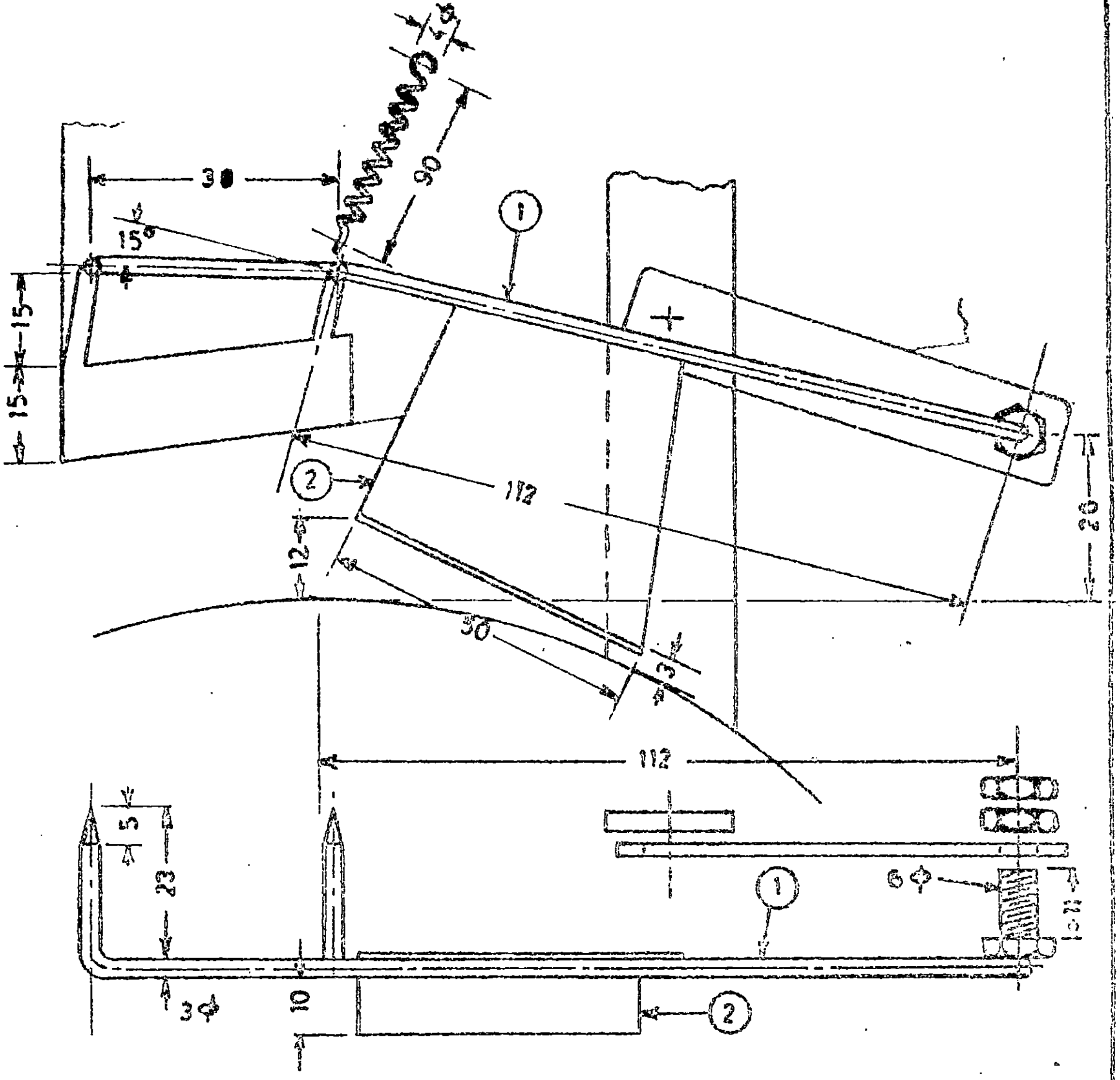
FIG.3.5. DETAILS OF THE SEEDLING RAKE



1. Nails of the seedling rake
2. Slits in the bottom of the box
3. Seedling box opening

FIG. 3.6 Seedling rake - plan

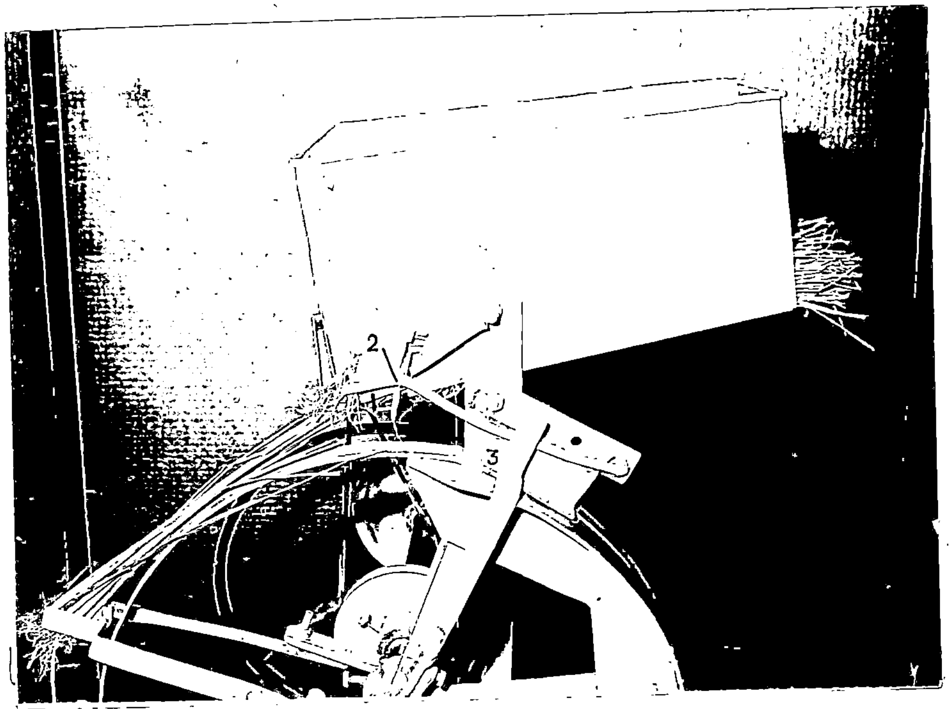
of cranks, each of 1 cm radius. The cranks were so positioned that the upper half of the circular locii of the nail tips projected above the bottom plate of the seedling box through the slits provided as shown in Fig. 3.6. They rotated clockwise when viewed from rear, so that the seedlings were moved towards the opening at the right side of the box. Trials showed that this arrangement was the most satisfactory one. Even though this moved the seedlings to the opening, to enable the pickers to take out the seedlings without missing, it was essential to employ a seedling ejector (Fig. 3.7). This was a spring loaded, pivoted rod of 3 mm diameter, welded with a plate-cam of 14G. M.S. sheet. This was positioned in such a way that this could be moved down by the pickers forcing the seedlings right into the jaws of pickers, ensuring positive gripping every time as depicted in Fig. 3.8. The cranks of the rake were joined through a coupling rod of 3 mm diameter (Fig. 3.5). A 5 mm diameter endless leather rope and a pulley arrangement was used to drive thr rake from the main shaft of the transplanting mechanism, at a speed twice that of the main shaft. This speed ratio was found to be optimum when tried with different speed ratios of 1.5, 1.75, 2.00 and 2.25 between main shaft and seedling rake. The crank radius of 1 cm was also selected after trials with cranks of 0.75 cm, 1.00 cm and 1.25 cm radii. The bottom of the box was provided with slopes of 4.8^{o} longitudinally and 5.7^{o} transversely as shown in Fig. 3.2, so that the roots of the seedlings remained



1. Seedling ejector   2. Cam for seedling ejector

Dimensions in mm

FIG.3.7.DETAILS OF THE SEEDLING EJECTOR



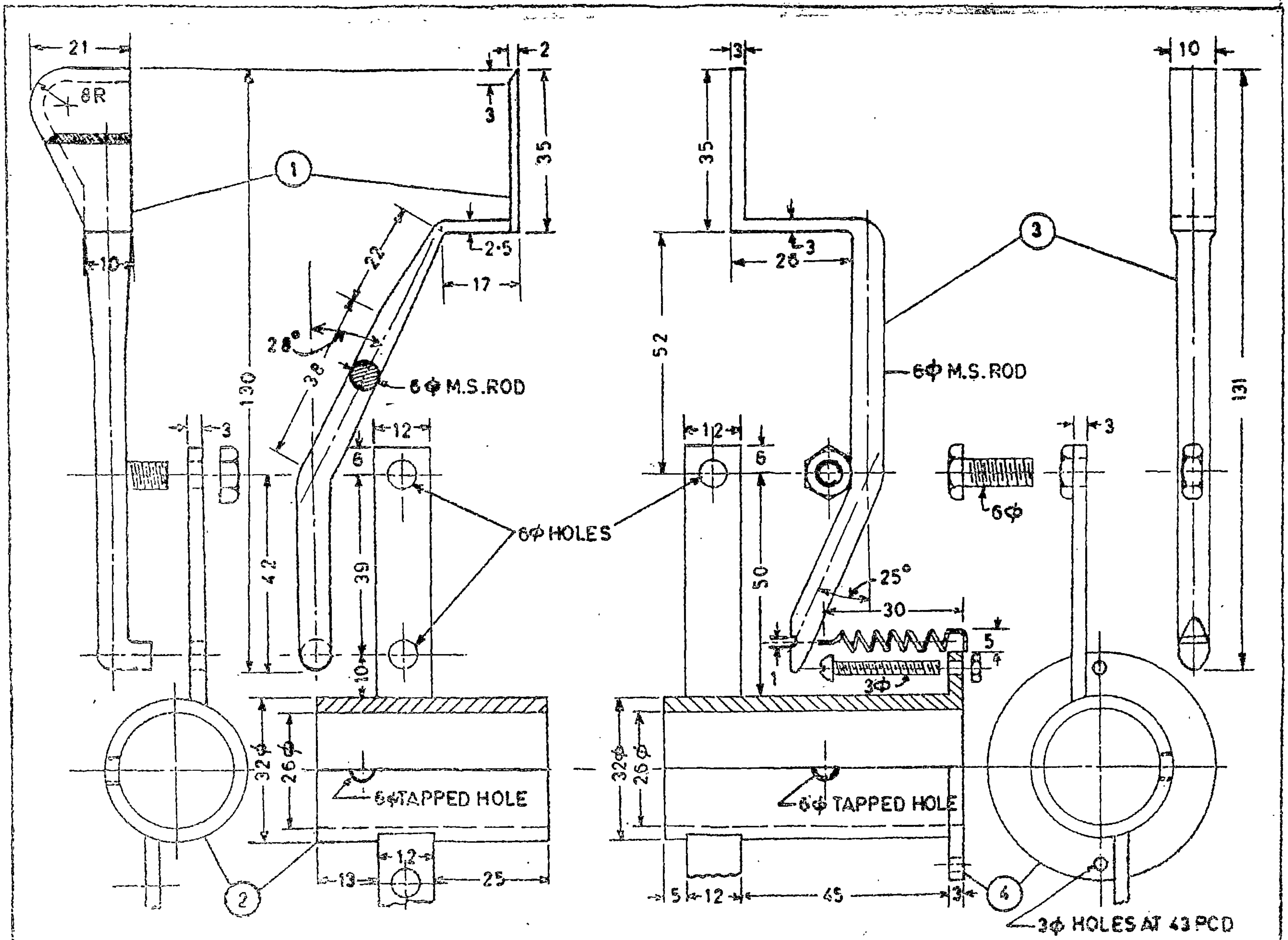
1. Seedlings
2. Seedling ejector
3. Plate cam of ejector

FIG. 3.8 Operation of the seedling ejector uniform at the rear-most end of the box and were moved regularly to the opening.

3.1.2 Seedling picking and releasing system

The seedling picking and releasing system comprised the sets of seedling pickers mounted on the main shaft and a stationary plate cam mounted on the main frame.

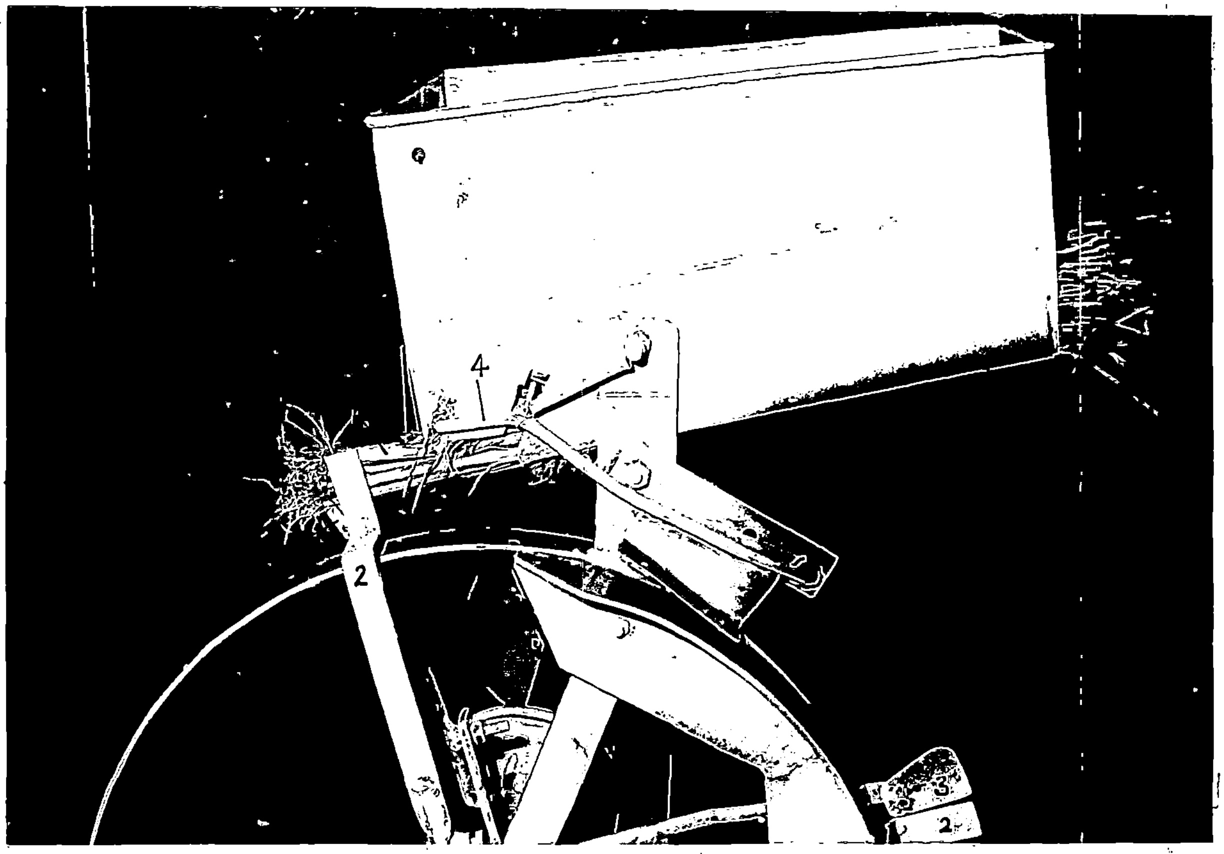
3.1.2.1 Seedling picker sets: Each set of the picker consisted of two members namely one fixed and another pivoted and spring loaded at one end. These are shown in Fig. 3.9. The pickers were made of 6 mm diameter M.S. rod. Two spiders, each consisting of a hollow boss of 3 mm thickness, carrying two arms of M.S. flat welded to the boss to mount the pickers radially, were provided. The fixed picker that passed through the seedling box had a flat scraper with a curved and chamfered leading edge. This enabled the pickers to take out the seedlings even if the roots were slightly entangled or interwoven, without any bending of the stem. In the initial design the width of both the picker heads were kept 10 mm, but this caused bending of the stem as the roots were entangled. The picking end of the pivoted picker was flattened to improve the gripping and to reduce the pressure on the seedlings. The other end was connected with a tension spring to the flangedend of the boss through a machine screw and nut so that the force at the picking end could be



1. Fixed picker   2. Spider for fixed picker   3. Pivoted picker   4. Spider for pivoted picker

Dimensions in mm

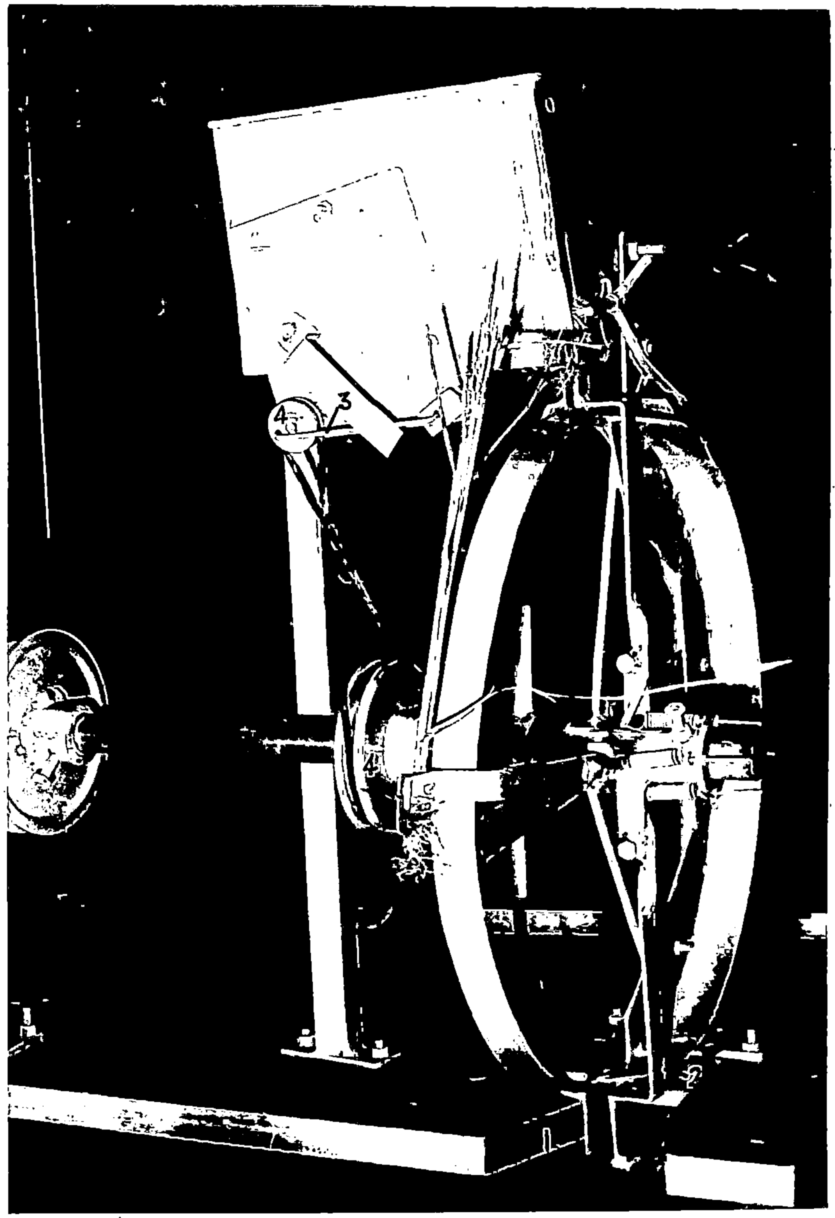
FIG.3.8. DETAILS OF THE SEEDLING PICKER ASSEMBLY



1. Seedlings
2. Pivoted picker
3. Fixed picker
4. Seedling ejector

FIG. 3.10 Grasping the seedlings by pickers adjusted to obtain better picking with minimum damage. The bosses of the spiders were provided with 6 mm tapped holes, to secure them firmly with the main shaft, by bolts. The main shaft was turned and finished to a diameter of 26 mm. It was hollow with a thickness of 3 mm. It was supported by a pair of brass bushes. The dimensioned exploded view of the picker assembly is shown in Fig. 3.9 and its operation explained in Figs. 3.10 and 3.11.

3.1.2.2 Main frame and the stationary cam: The main frame consisted of a circular member made of 25 mm x 5 mm M.S. flat, and a main support made of 50 mm x 6 mm M.S. flat, both being welded together to form an integral part (Fig. 3.12). The diameter of the circular member was kept as 230 mm as the length of arc between the points of picking and releasing was 35 cm. This accomodated a maximum seedling length of 30 cm with a clearance of 5 cm. The circular member also guided the seedlings pulled out of the tray, which in turn avoided any bending or breaking. One of the two bush bearings was provided at the centre of this member to support the main shaft. The main support was bolted to a wooden float at the bottom. This had a thickness of 30 mm and width of 360 mm with 100 mm high front fender of G.I. sheet of 26 G, to prevent water flowing over the float. The axis of the main shaft was 12 cm above the top of the float (Fig. 3.12). A cam of 325 mm length and 33 mm width made out of 3 mm thick M.S. sheet was provided to open



1. Seedling released
2. Cam opening the pivoted picker
3. Coupling rod of seedling rake
4. Pulley-drive for seedling rake

FIG. 3.11 Releasing the seedlings by pickers and close the pickers. An inclination of 30° with the direction of travel of the pickers, provided at the ends of the cam, was found to be ideal for satisfactory operation of the pickers. This was selected after testing different inclinations from 25° through 40°. An inclination of 40° offered greater resistance to rotation of the pickers, while a lower inclination of 25° resulted in delayed opening and irregular release of the seedlings.

3.1.3 Seedling planting system

The seedlings released through the open trapezoidal slot in the wooden float were expected to be laid in a horizontal posture in the puddled field. The slot in the float was 30 cm long with a width of 9 cm at the front and 14 cm at the rear.

In order to incorporate a suitable planting finger, seedlings were placed on the puddled soil and then these were pressed down at about 1 cm above the roots by a 'L' shaped rod. This helped to plant the seedlings at an angle of 60° to 80° with the horizontal. A planting finger of similar shape and of 11 cm length made of 5 mm x 3 mm M.S. flat was pivoted on the circular frame of the mechanism (Fig. 3.12). The upper end of this finger was spring loaded. The pivot point and length of the planting finger were selected in such a way that, on release, the finger touched the seedlings lying on the puddled soil at about 1 cm above the roots and as the machine moved

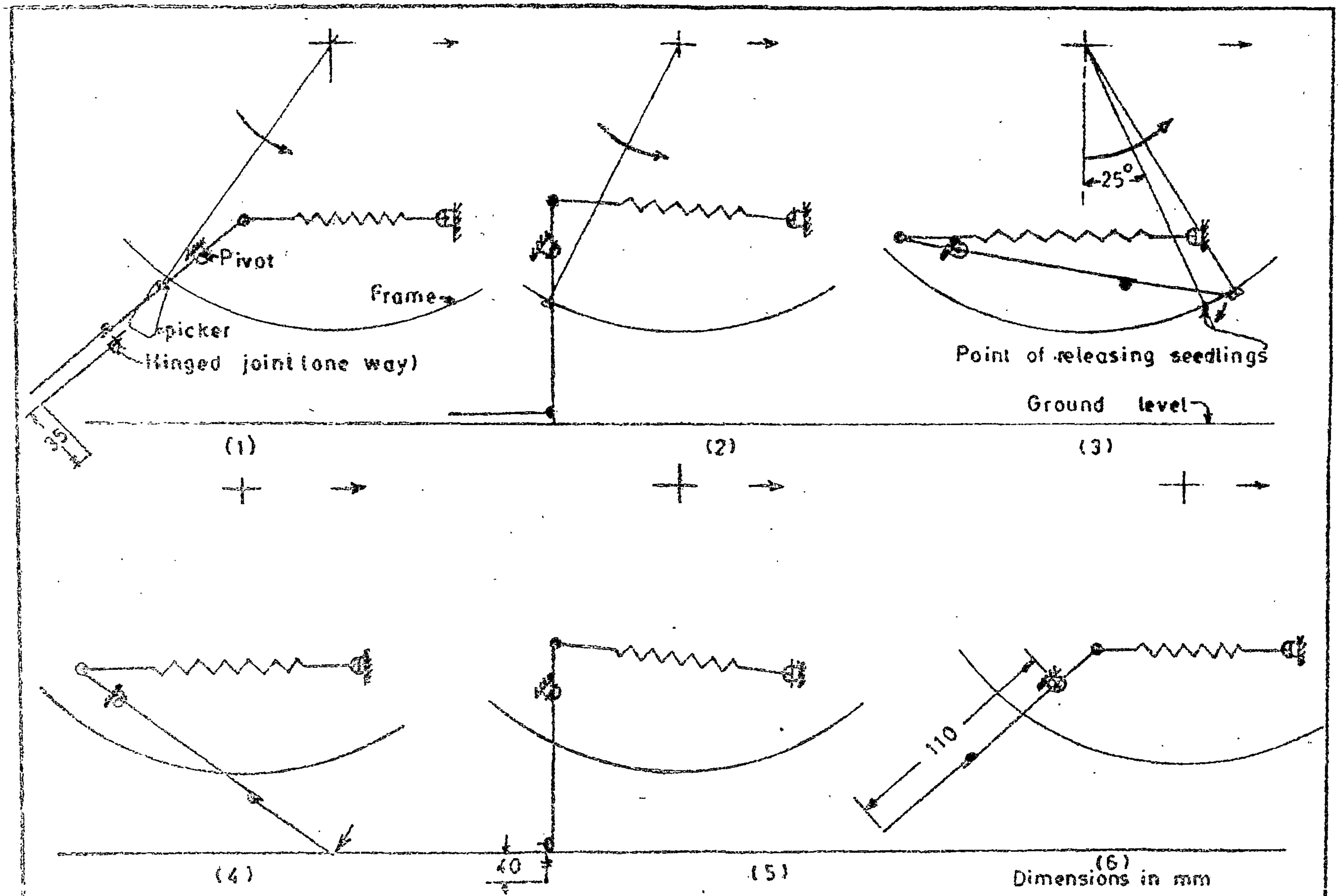


FIG.3.13 OPERATION OF THE PLANTING FINGER

forward, the seedlings were pressed down to a depth of about 4 cm. Fig. 3.13 shows the schematic of the operation of the planting finger.

3.1.4 Constructional details of mechanism-B

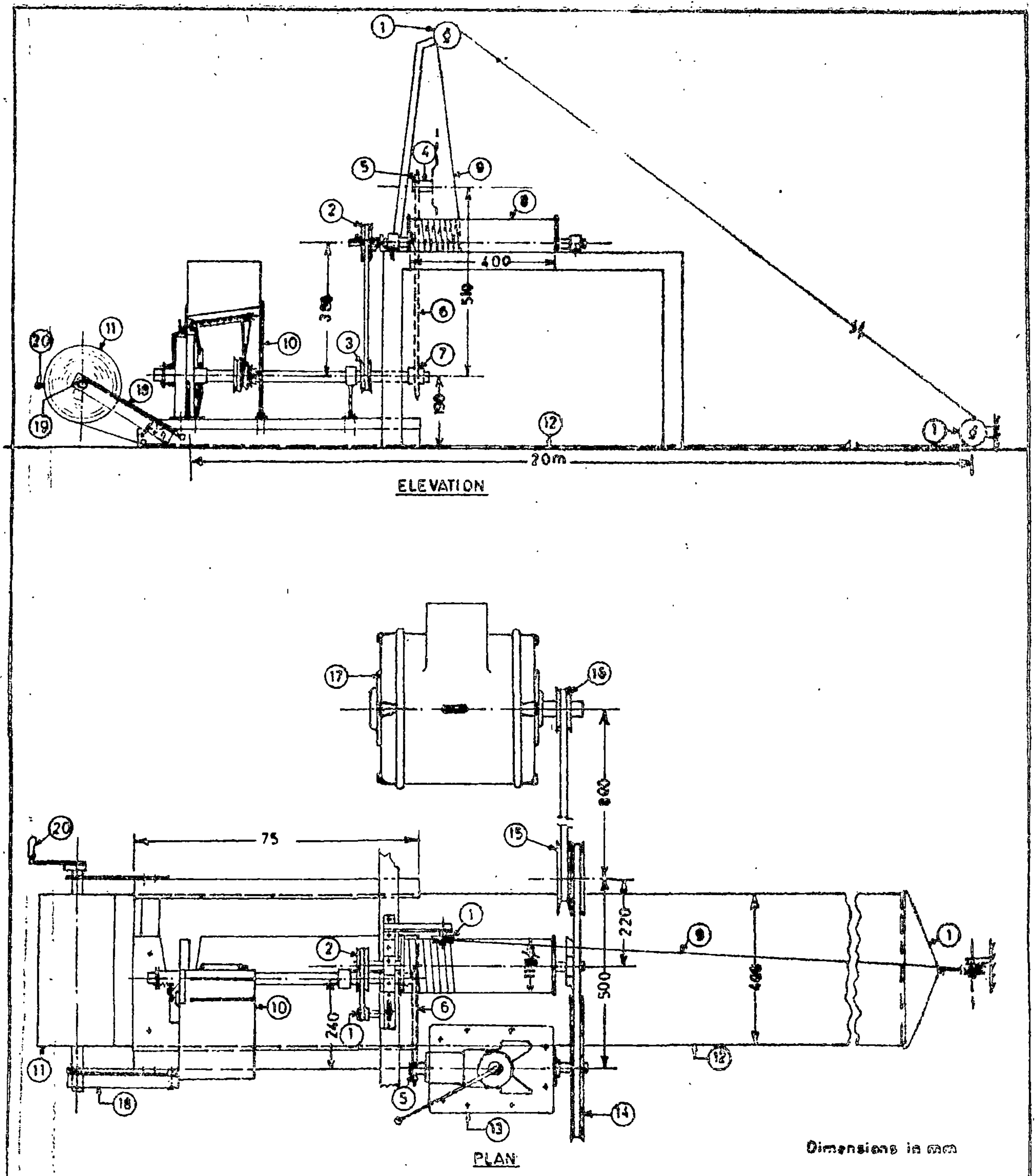
The mechanism developed initially and described hitherto had only two sets of pickers. Since the rotary speed of the pickers was inversely proportional to the number of pickers for the same field capacity and the tip velocity of the pickers was evidently an important factor affecting the missing and damage, it was decided to design and fabricate a second mechanism, with four picker sets having reduced tip velocity, to study the effect of lower tip velocity on the performance of the transplanter. This mechanism was based on the same concept as mechanism-A, but to accomodate four picker sets the diameter of the circular member and stationary cam was increased to 400 mm against 230 mm for mechanism A. The dimensions of the pickers were also increased proportionately, but those of the picking ends were kept unaltered. The pivoted pickers were made of 20 mm x 3 mm M.S. flat with stronger springs of 1.5 mm wire, but their securing arrangement was the same as for mechanism-A, so that the tension was adjustable. The fixed pickers were made of 12 mm M.S. rod. The speed ratio between the main shaft and seedling rake was also increased to 4, using a driving pulley of 10 cm diameter. All other components like main shaft, seedling box, seedling rake, bearings, wooden float, seedling ejector etc. were kept of the same specifications as for transplanting mechanism-A. Fig. 3.14 shows the details of this mechanism.

3.3 Test Set-up and Procedures

Testing of the two transplanting mechanisms was carried out mainly in the laboratory but a limited trials were also attempted in the field.

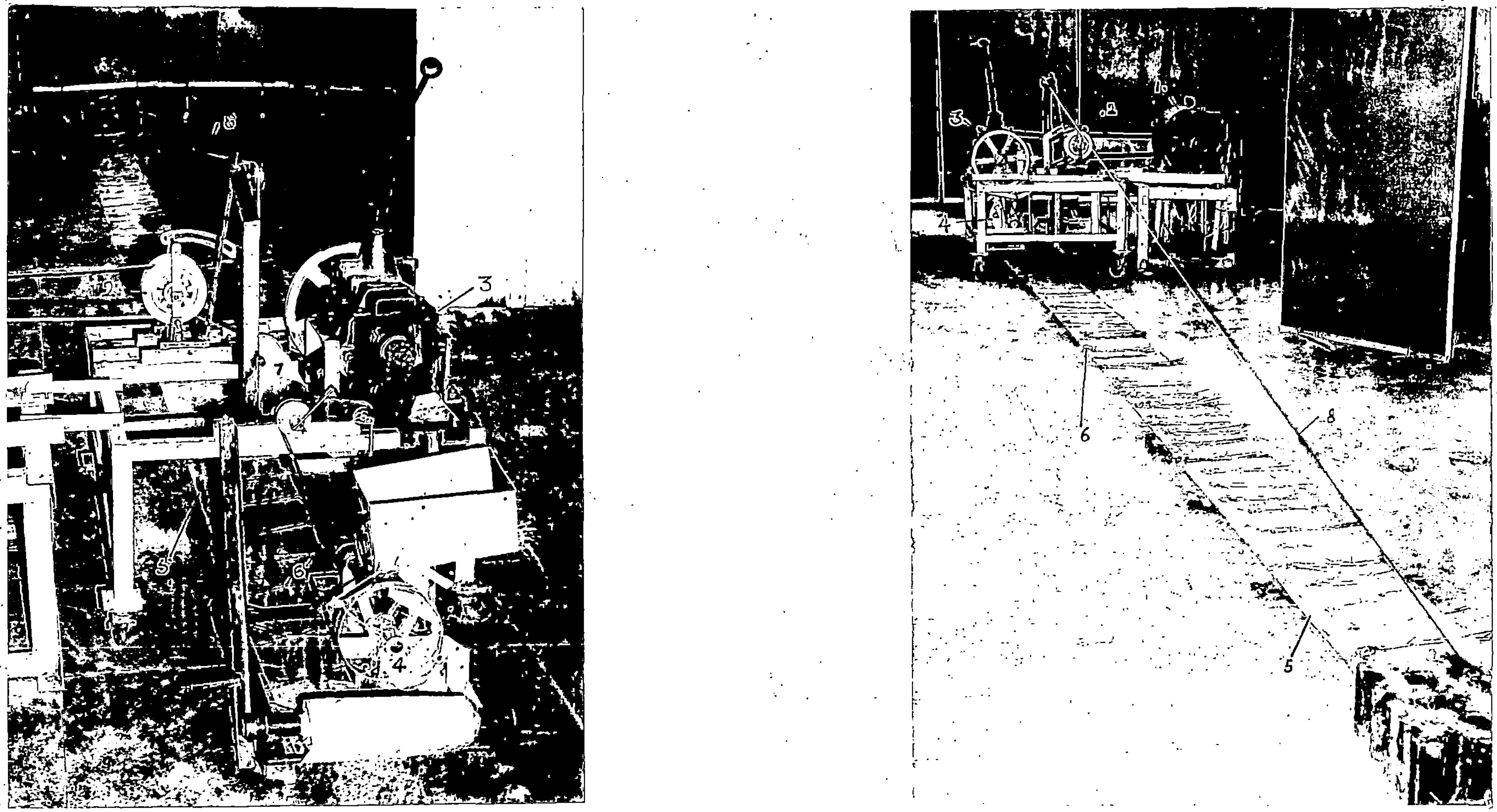
3.3.1 Laboratory test set-up

The laboratory tests were aimed at to study the performance of the two mechanisms in respect of the picking and releasing of the seedlings. A test set-up was designed and fabricated for this purpose. As suggested by previous researchers it was decided to observe the performance of the mechanism for a minimum of 100 strokes of continuous running. The test set-up was, therefore, provided with canvas conveyor of 20 m length capable of holding about 125 seedling hills released by the mechanism with provision to unwind and rewind it for each test. The details of this set-up are shown in Figs. 3.15 and 3.16. The set-up comprised a variable speed unit to drive the conveyor and the transplanting mechanism synchoronously at different speeds, a M.S. angle frame to clamp the mechanism being tested and a winding drum to unfold the conveyor.



1. Idler pulleys 2. V-Belt pulley, 85 ϕ 3. V-Belt pulley, 80 ϕ 4. Output shaft–gear box 5. Driving sprocket-15T 6. Roller chain 7. Driven sprocket, 20T 8. Rope winding drum 9. Nylon rope 10. Transplanting mechanism 11. Canvas roll 12. Canvas conveyor 13. Gear box 14. V-Belt pulley, 360 ϕ 15. Floating centre 16. V-Belt pulley, 115 ϕ 17. Elector motor 18. Speed controller-conveyor 19. Friction lining 20. Handle

FIG 3.15. LABORATORY TEST SET-UP



(a) View from mechanism side (b) View from conveyor side

1. Electric motor 2. Floating centre 3. Gear box 4. Transplanting mechanism 5. Canvas conveyor 6. Seedlings released in hills 7. Winding drum 8. Nylon rope

FIG. 3.16 Laboratory test set-up in operation

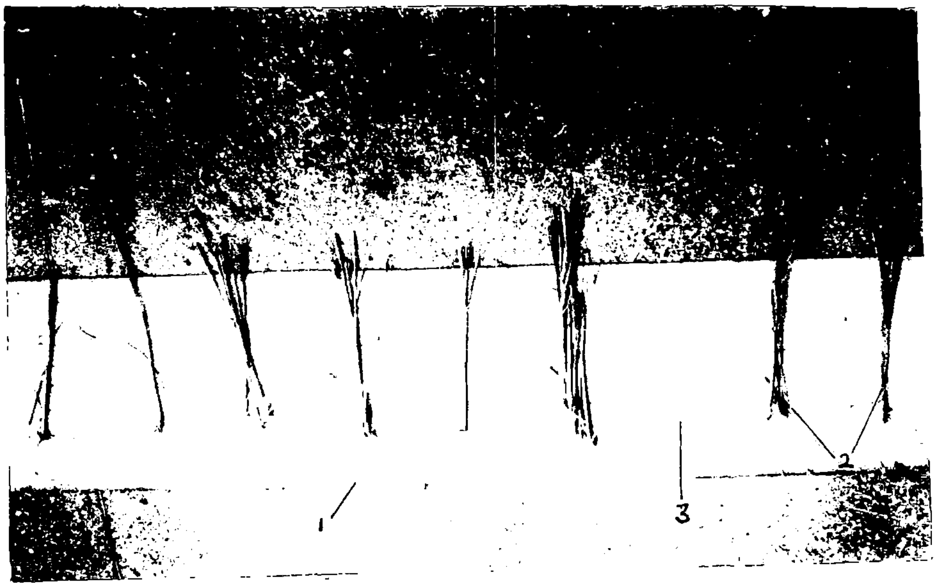
3.3.1.1 Variable speed drive: The variable speed drive consisted of an electric motor, a floating centre vari-speed pulley and a five-speed gear box, all supported on a frame work (Fig. 3.15). Speeds ranging from 15 to 1075 rpm could be achieved at the output shaft of the gear box corresponding to motor speed of 960 rpm. The specifications are given vide Appendix-B. The gear box had provision to engage and dis-engage the power to drive the transplanting mechanism at the required speed. The output shaft of the gear box and main shaft of the transplanting mechanism were connected through a pair of sprockets and a roller chain of 12.5 mm pitch. The driving sprocket had 15 teeth and the driven sprocket, secured by bolt to the main shaft of the mechanism, had 20 teeth. The transplanting mechanism was mounted on a M.S. angle frame, using 6 mm bolts. The frame composed of two angle iron members each of size 50 x 50 x 6 mm and 750 mm long which were joined by two M.S. flats of 50 x 6 x 500 mm size. The frame was kept on the floor (Fig. 3.15).

3.3.1.2 Conveyor arrangement: A canvas conveyor of 40 cm width and 20 m length was used to retain the seedlings released by the pickers of the transplanting mechanism. The canvas was wrapped over a 25 mm diameter hollow shaft, held on the supports fixed to the frame. The outer end of the canvas was tied to a rope that passed over an idler pulley of 60 mm diameter, fixed at a distance of about 20 m from the mechanism (Fig. 3.15).

The other end of the rope was tied to the winding drum, by changing its direction with the help of an idler. The winding drum was supported on two bearings mounted on the same frame as the variable speed drive. The drum was driven by a V-belt and pulley drive from the main shaft of the mechanism. The speed ratio was selected such that the seedling hills were released at a regular spacing of about 15 cm, so that the missing hills, if any, could be easily counted. Fig. 3.17 shows a section of the conveyor holding seedlings. The driving pulley was secured to the main shaft of the mechanism using 6 mm bolt. At one end of the canvas-roll shaft a spring loaded friction lined brake was provided to achieve constant speed of the conveyor, as it was pulled over the floor. The re-winding of the canvas was done with a hand crank at the other end of the canvas-roll shaft.

3.3.2 Test Procedure

3.3.2.1 Preparation of seedlings: Seedling grown in the convetional nursery were used to study the performance of the mechanisms. The roots of the seedlings were washed to remove the mud. The leaves were pruned to the heights of 20, 25 and 30 cm, as required for the test. The bunch of seedlings were separated, but their roots were not cut. These seedlings were then loaded in the seedling box.



1. Canvas
2. Seedling hills
3. Plant hill missing

FIG. 3.17 Portion of the conveyor holding seedling hills

1. Splitting of stem
2. Damage to lower leaf
3. Bending of stem

FIG. 3.18 Damaged seedlings

3.3.2.2 Method of the test: Before the start of each test the canvas was wound completely on the roll. The driven sprocket was kept loose on the main shaft by unscrewing the securing bolt. The motor was started and the speed of the driving sprocket was measured with the help of a hand-tachometer.

Adjusting the floating centre and selecting the suitable gear, the speed of the main shaft was set to 15, 22.5, 30, 37.5, 45, 60 or 75 rpm, as required to suit the treatment combinations. The motor was then run for about five minutes to ensure the stabilisation of the adjusted speed. The gear was then kept in neutral and the driven sprocket was secured to the main shaft. The gear was re-engaged and the transplanting mechanism and the winding drum were both operated, resulting in the picking of the seedlings from the seedling box and placing them on the canvas-conveyor, whose movement was properly synchronised with the speed of the transplanting mechanism. When the conveyor was completely stretched, the gear was disengaged thereby cutting the drive to the transplanting mechanism and the winding drum. The following observations were taken:

1. Rate of picking the seedlings in hills/min
2. Number of seedlings in each hill
3. Number of damaged seedlings in each hill

4. Time taken for one revolution of the energy meter disc when the mechanism was in operation in seconds
5. Time taken for one revolution of the energy meter disc when the mechanism was not in operation in seconds.

These observations were taken to evaluate the performance of the transplanting mechanisms with respect to the following indices:

1. Percentage of missing hills
2. Seedling distribution and average number of seedlings/hill
3. Percentage of seedling damage
4. Power consumption of the mechanisms.

The damaged seedlings were distinguished by visual observation. Fig. 3.18 shows a group of damaged seedlings (definition vide Appendix-A).

3.3.3 Test conditions and variables studied

Variables which had bearing on the performance of the transplanting mechanism were indentified as follows:

Variables relating to seedlings

1. Seedling age
2. Diameter and length of seedling stem
3. Length and number of roots

Variables relating to mechanism

1. Geometry of the picker jaw
2. Number of pickers and their speed
3. Geometry of the seedling rake
4. Geometry of the seedling ejector
5. Slope and size of seedling box
6. Size of opening of the seedling box
7. Quantity of seedlings in the box
8. Position of points of picking and releasing
9. Rate of picking

Variables relating to field

1. Type of soil
2. Depth of standing water
3. Degree of puddle

The variables relating to seedlings and mechanism will affect the seedling damage, number of seedlings/hill, ability of the mechanism to take out 2 to 3 seedlings from the seedling box and to release them, where as the variables relating to field will affect the depth and angle of planting. However, the study reported in this thesis was confined to three variables only, namely, rate of picking, seedling height, and number of pickers. Table 3.1 shows the test conditions of these variables.

It was obvious that the performance indices, namely the seedling distribution, plant hill missing and seedling damage would be influenced, among other variables, by the tip velocity of the pickers as the time available to pick the seedlings varied inversely as the tip velocity. For the sake of comparison of the two mechanisms and to decide which of the two mechanisms was superior in performance, it was decided to test both of them against a given rates of picking. This was done as the ultimate objective was to evolve a mechanism with minimum seedling damage, plant hill missing and recommended number of seedlings/hill with maximum field capacity. As the number of pickers and their length were fixed in each mechanism, the tip velocity of the pickers remained directly proportional to the rate of picking

As shown in Table 3.1, 35 to 40 days old seedlings of PR-106 paddy variety were used for the laboratory test. Two mechanisms, each at four different speeds were tested.

Table 3.1 Test conditions and variables

Sr. No.	Variables	Levels of variation
1	2	3
1.	Seedlings	
	(a) Paddy variety	One; PR-106
	(b) Age (days)	One; 35 to 40
	(c) Height (cm)	Three; 20, 25 and 30
2.	Transplanting mechanism	Two; with two pickersets and four picker-sets
3.	Rate of picking the seedlings (hills/min)	Four; 60, 90, 120 and 150

The study was planned with a 4 x 3 x 2 factorial experiment on a randomized block design, the factors being rate of picking at four levels (P = 4), height of seedling at three levels (H = 3) and type of mechanisms at two levels (M = 2), with three replications (R = 3). There were 24 treatment combinations and 72 sets of observations to be made. After preparing the list of treatment combinations, these were randomised by drawing lots. The experiment was then carried out in accordance with the procedure outlined under section 3.3.2.

3.3.4 Field test

Mechanism-A was also tried in the puddled soil, firstly in a tray of 1.5 x 0.5 m size with 15 cm depth filled with puddled soil to simulate almost a field condition. It was later tried to a limited extent in the actual field, puddled with a power tiller. The standing water ranged from 0.0 to 2.5 cm in one test and 2.8 to 4.2 cm the second. However, the field tests could not be pursued due to many problems, discussed in Chapter IV.

Chapter IV

RESULTS AND DISCUSSION

This chapter presents the results of the testing of the transplanting mechanisms designed and developed for this study. The results and discussion have been arranged under the following headings:

1. Effect of rate of picking on seedling distribution, plant hill missing, seedling damage and power consumption
2. Effect of seedling height on seedling distribution, plant hill missing, seedling damage and power consumption
3. Effect of the mechanisms on seedling distribution plant hill missing, seedling damage and power consumption.

4.1 Effect of Rate of Picking

The effect of the four levels of rate of picking on the following indices was studied:

4.1.1 Seedling distribution: The percentage of hills with 0, 1, 2 to 4 and 5 to 8 seedlings in each hill was computed and tabulated vide Appendix-F. The results are represented in Figs. 4.1 through 4.9. Though the mechanism was designed to pick 2 to 3 seedlings/hill, 2 to 4 seedlings/hill was reported to be well within the acceptable limits (4, 9, 40). It was found that 50.4 to 82.67 per cent of the hills contained 2 to 4 seedlings/hill. The statistical analysis presented vide Table 4.1 indicated that the rate of picking was significant at 5 per cent level, with respect to average number of seedlings per hill. Both the first order interactions viz. speed x seedling height and speed x mechanism, as well as second order interaction viz., speed x seedling height x mechanism were also significant at 5 per cent level. The critical difference at 5 per cent level of significance was also calculated and compared with the treatment mean differences. This showed that there was no significant difference between the rates of picking of 90 and 120 hills/min but between all other rates of picking the differences were significant at 5 per cent level. The average number of seedling per hill was between 1.7 and 2.6 as against the functional requirement of 2 to 3 of the mechanism.

The rate of picking was significant, because the time available for picking the seedlings from the box decreased as the rate of picking increased and this resulted in varying number of seedlings per hill as the rate varied. The nature

Table 4.1 Analysis of variance for average number of seedlings/hill

Source	d.f	S.S	M.S.S.	F_{obs}	F_{tab}
1	2	3	4	5	6
Replications (R)	2	0.0070	0.0035	0.3259	3.20
Rate of picking (P)	3	1.1228	0.3743	34.8538*	2.81
Height of seedlings (H)	2	0.8679	0.4340	40.4125*	3.20
Mechanism (M)	1	0.0176	0.0176	1.6389	4.05
Rate of picking x Height of seedling	6	0.2085	0.0348	3.2405*	2.30
Mechanisms x Height of seedling	2	1.0769	0.5385	50.1437*	3.20
Mechanisms x Rate of picking	3	1.8576	0.6192	57.6583*	2.81
Picking rate x seedling height x Mechanism	6	0.4678	0.0780	7.2632*	2.30
Error	46	0.4940	0.0107	-	-
Total	71	6.1201			

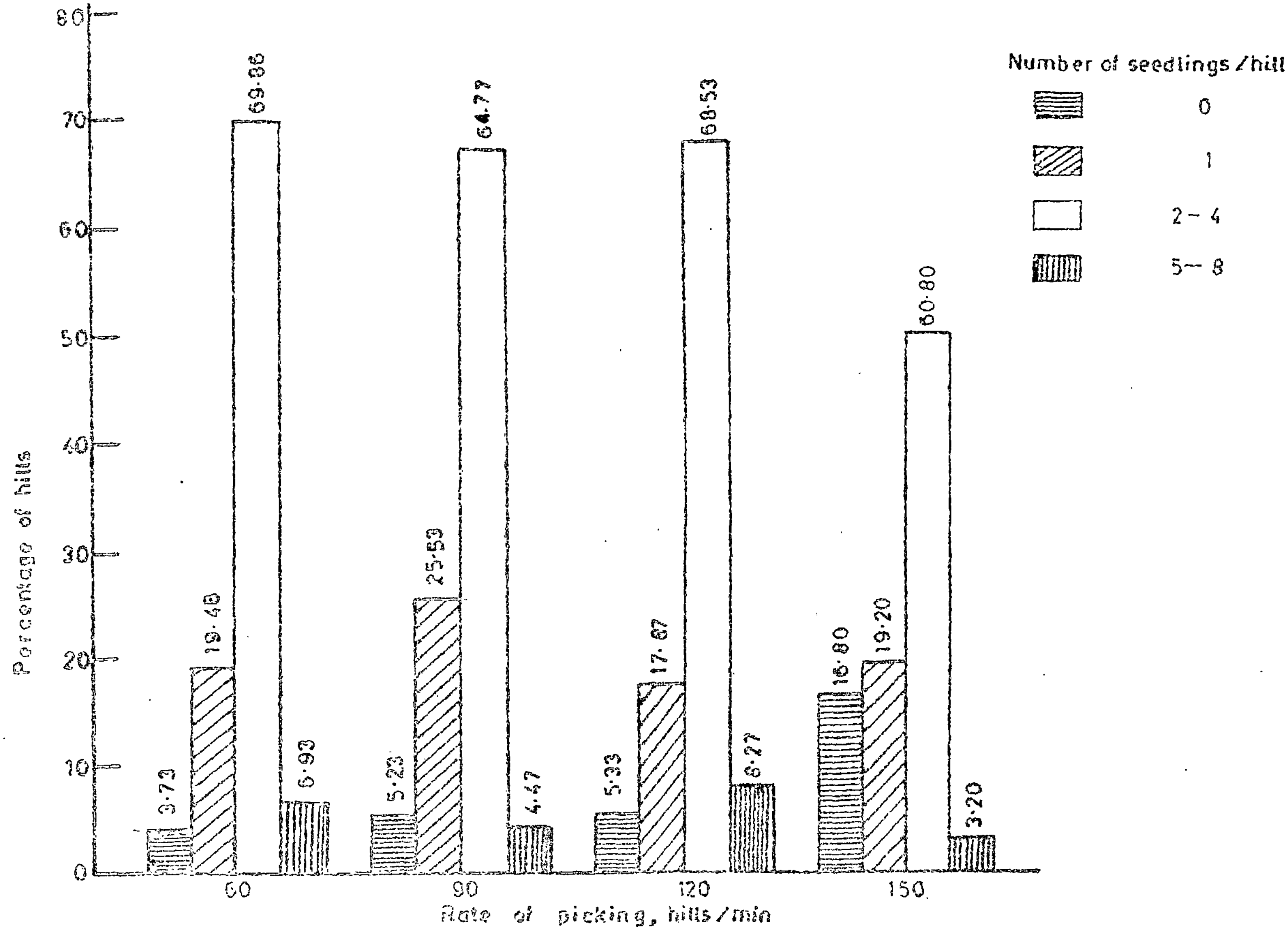


FIG.4.1 EFFECT OF RATE OF PICKING ON SEEDLING DISTRIBUTION FOR MECHANISM-A
(SEEDLING HIEGHT = 30cm)

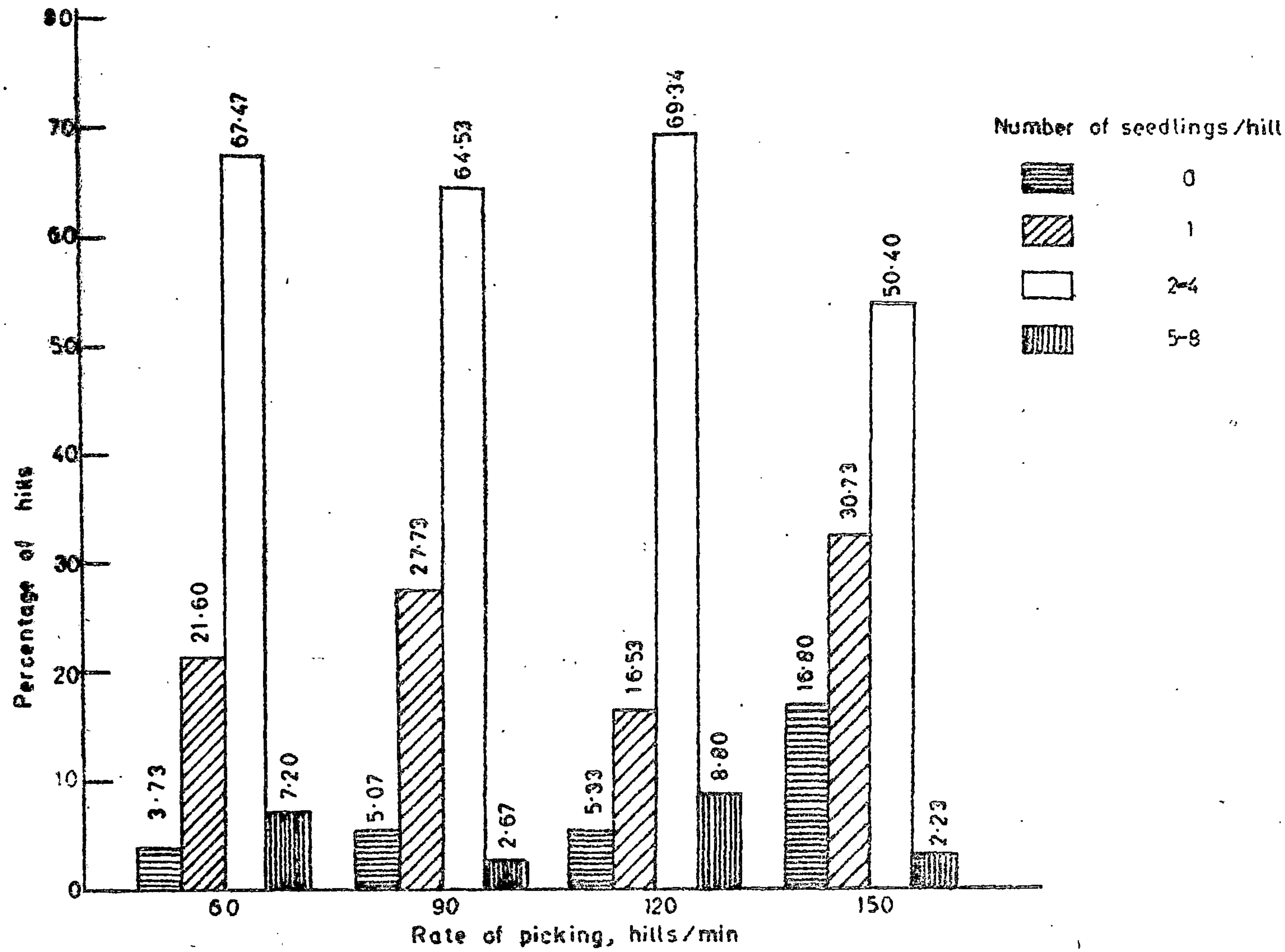


FIG.4.2 EFFECT OF RATE OF PICKING ON SEEDLING DISTRIBUTION FOR MECHANISM-A
(SEEDLING HEIGHT = 25 cm)

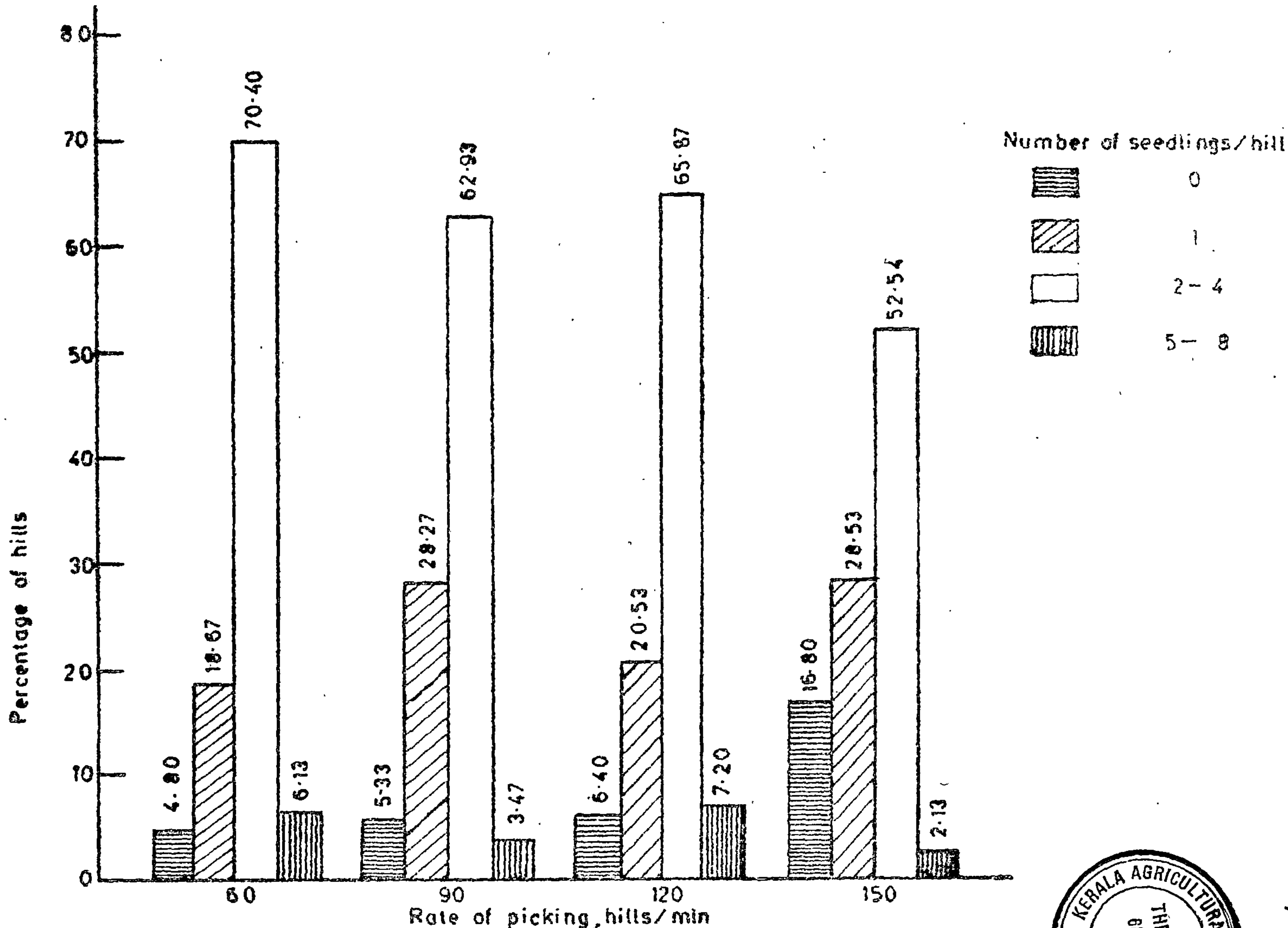


FIG.43 EFFECT OF RATE OF PICKING ON SEEDLING DISTRIBUTION FOR MECHANISM — A (SEEDLING HEIGHT = 20 cm)

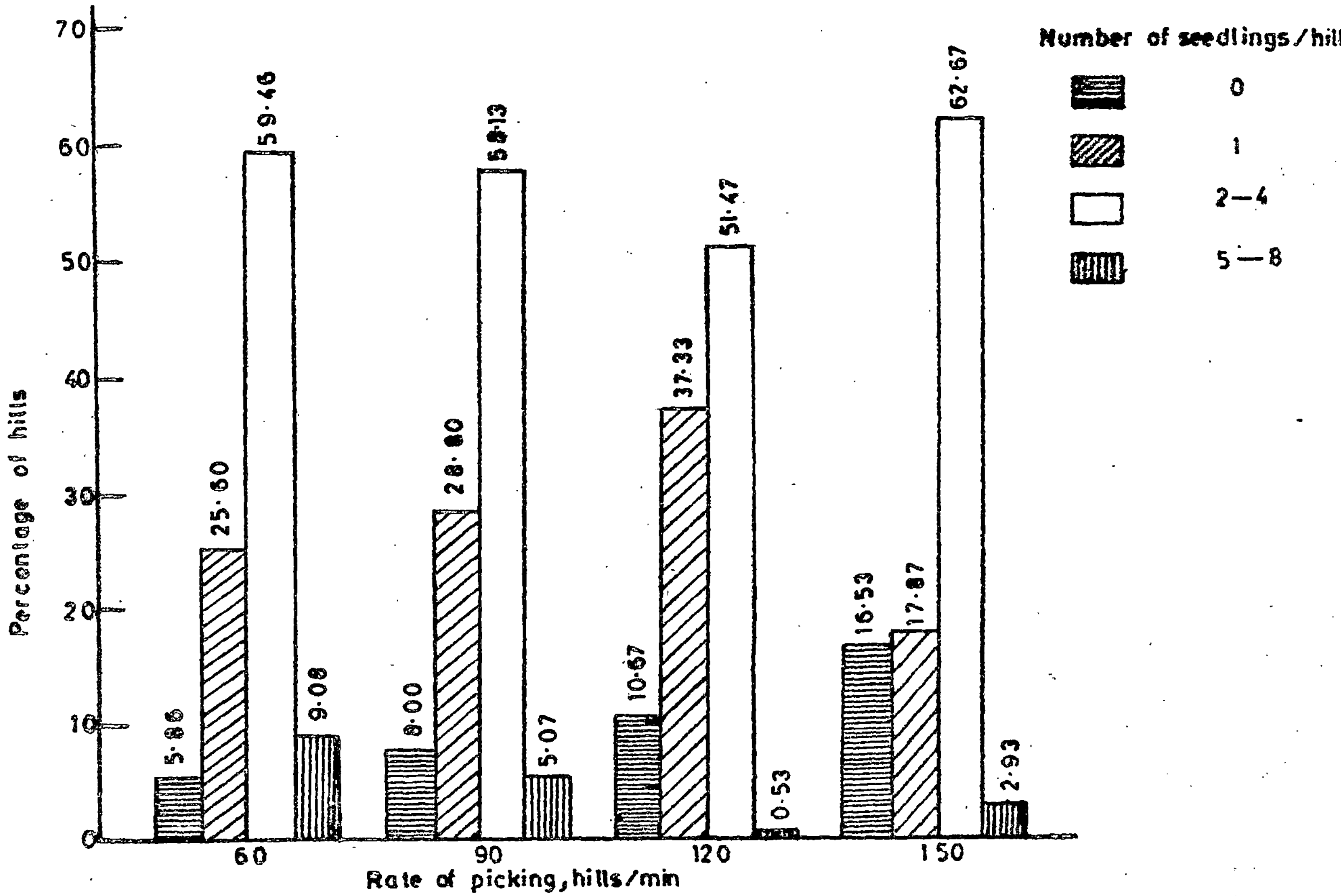


FIG.46 EFFECT OF RATE OF PICKING ON SEEDLING DISTRIBUTION FOR MECHANISM —B
(SEEDLING HEIGHT 30 cm)

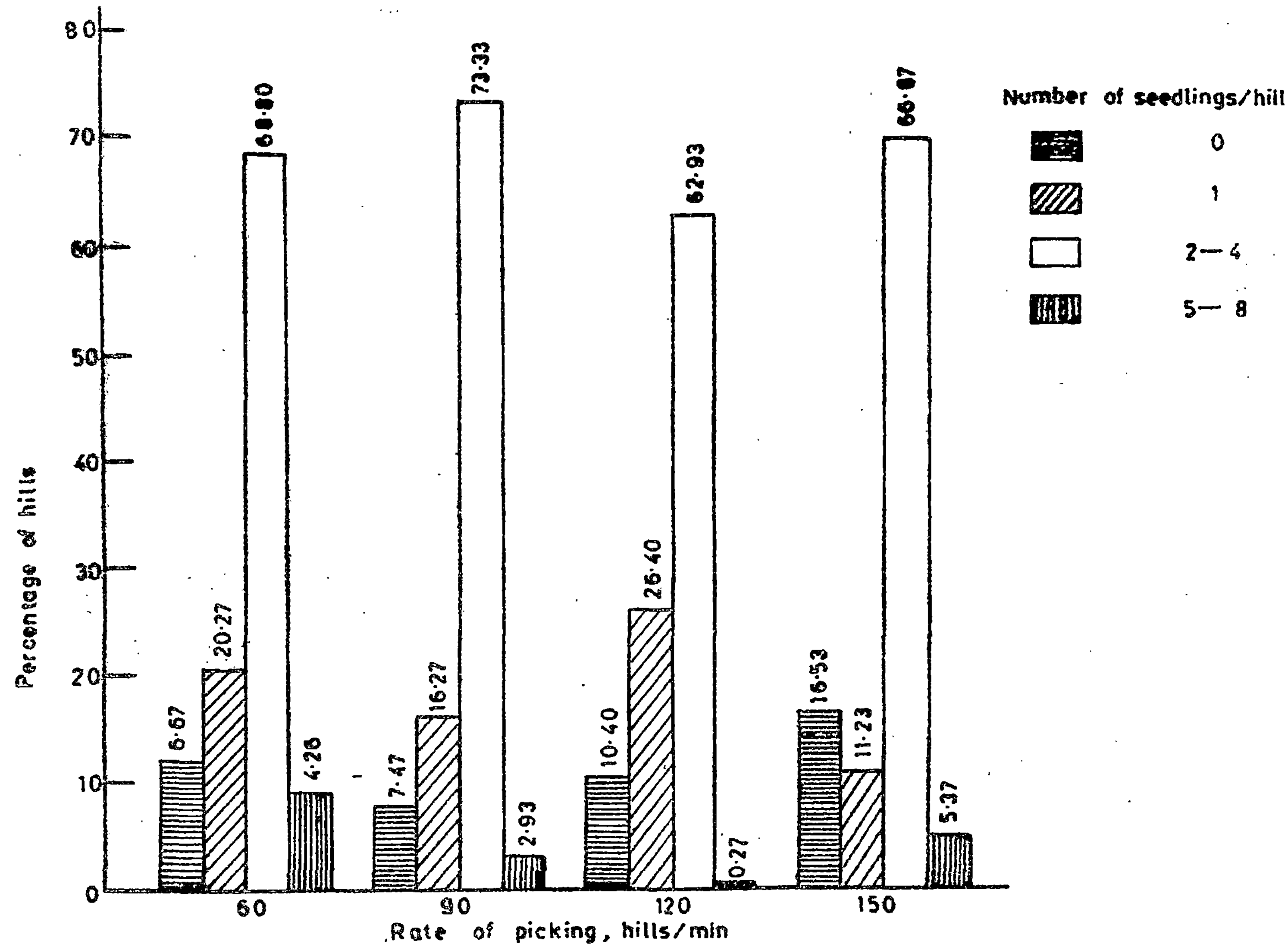


FIG 4.5 EFFECT OF RATE OF PICKING ON SEEDLING DISTRIBUTION FOR MECHANISM - B (SEEDLING HEIGHT = 25 cm)

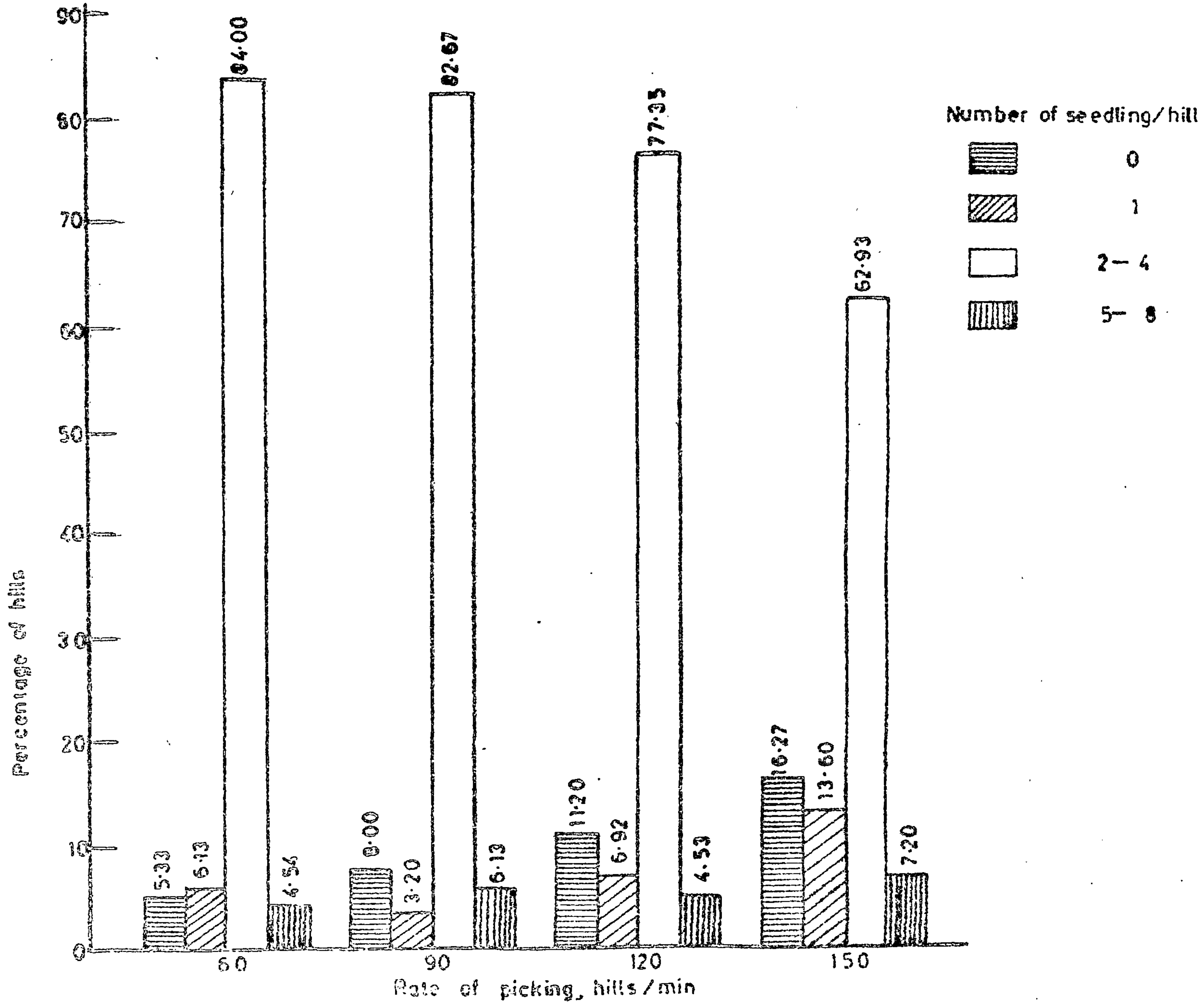
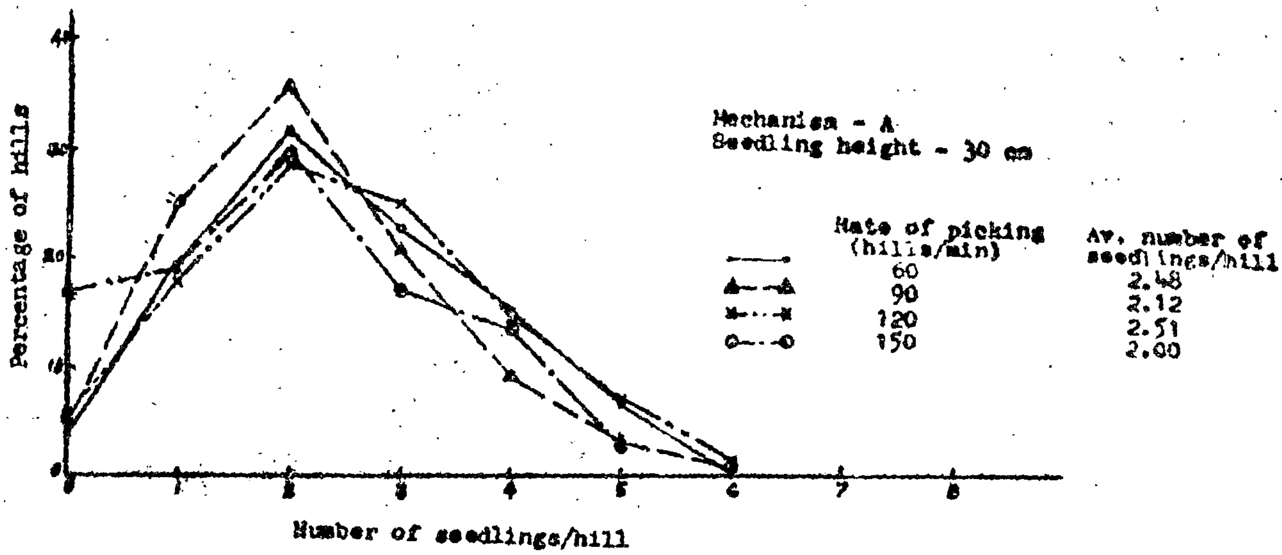
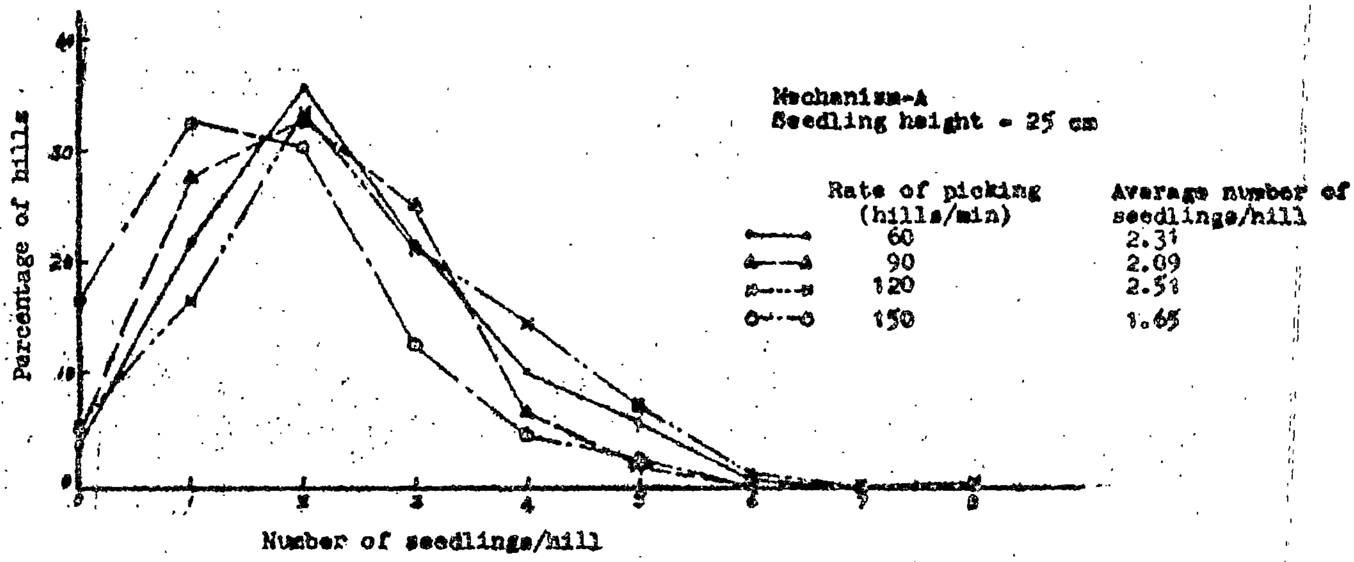


FIG.4.6 EFFECT OF RATE OF PICKING ON SEEDLING DISTRIBUTION FOR MECHANISM-B (SEEDLING HEIGHT 20 cm)

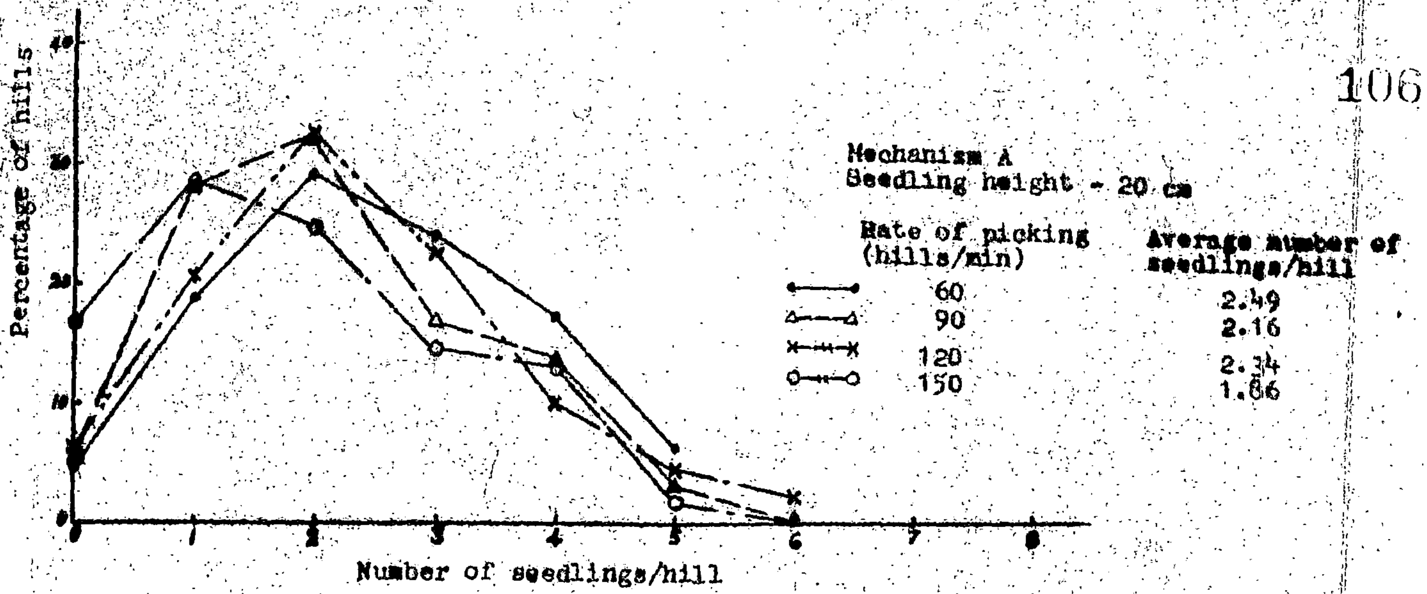


No. of seedlings/hill	0	1	2	3	4	5	6	7	8	Rate of picking
Percentage of seedling hills	3.73	19.47	31.73	22.67	15.47	6.67	0.26			60 hills/min
	5.07	25.33	35.73	20.53	9.07	3.47	0.80			90 hills/min
	5.33	17.87	28.8	25.07	14.67	7.20	1.07			120 hills/min
	16.80	19.20	29.87	17.07	13.87	3.20				150 hills/min

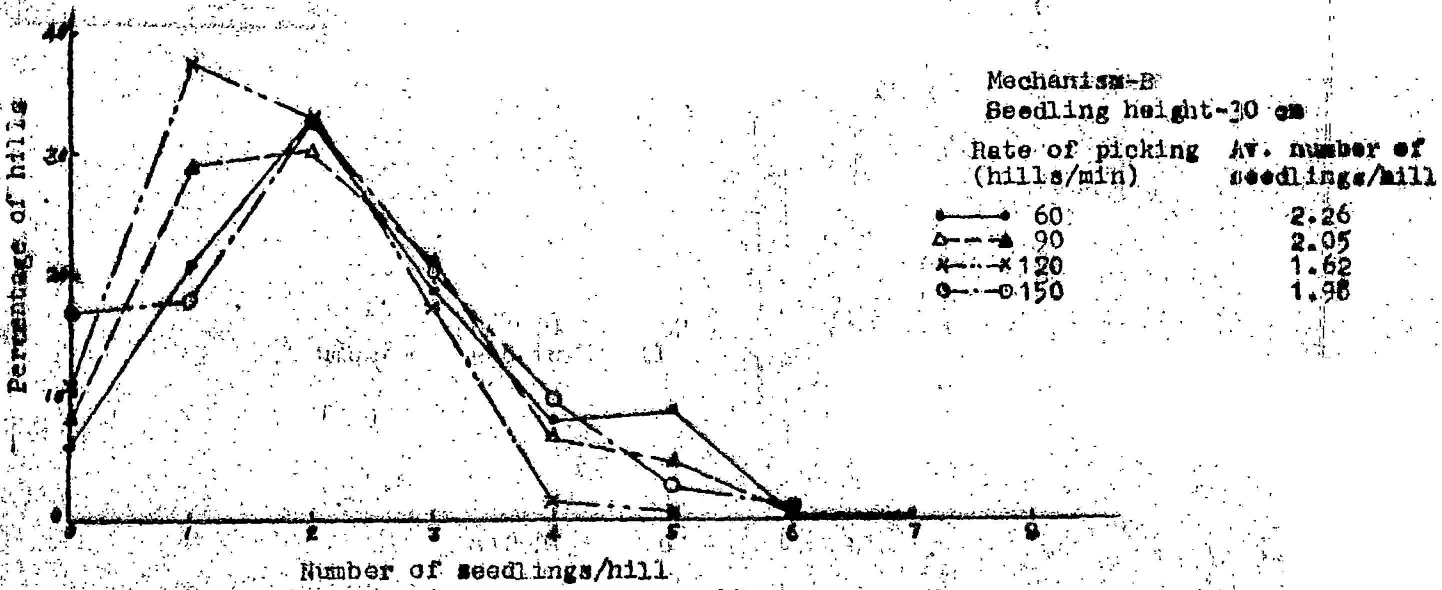


No. of seedlings/hill	0	1	2	3	4	5	6	7	8	Rate of picking
Percentage of seedling hills	3.73	21.6	35.73	21.6	10.13	5.87	0.80	0	0.53	60 hills/min
	5.07	27.73	32.57	25.33	6.67	2.40	0.26			90 hills/min
	5.33	16.53	33.60	21.07	14.67	7.47	1.07	0	0.26	120 hills/min
	16.8	32.53	30.40	12.53	4.80	2.67	0.26			150 hills/min

FIG. 4.7 SEEDLING DISTRIBUTION AT VARIOUS RATES OF PICKING

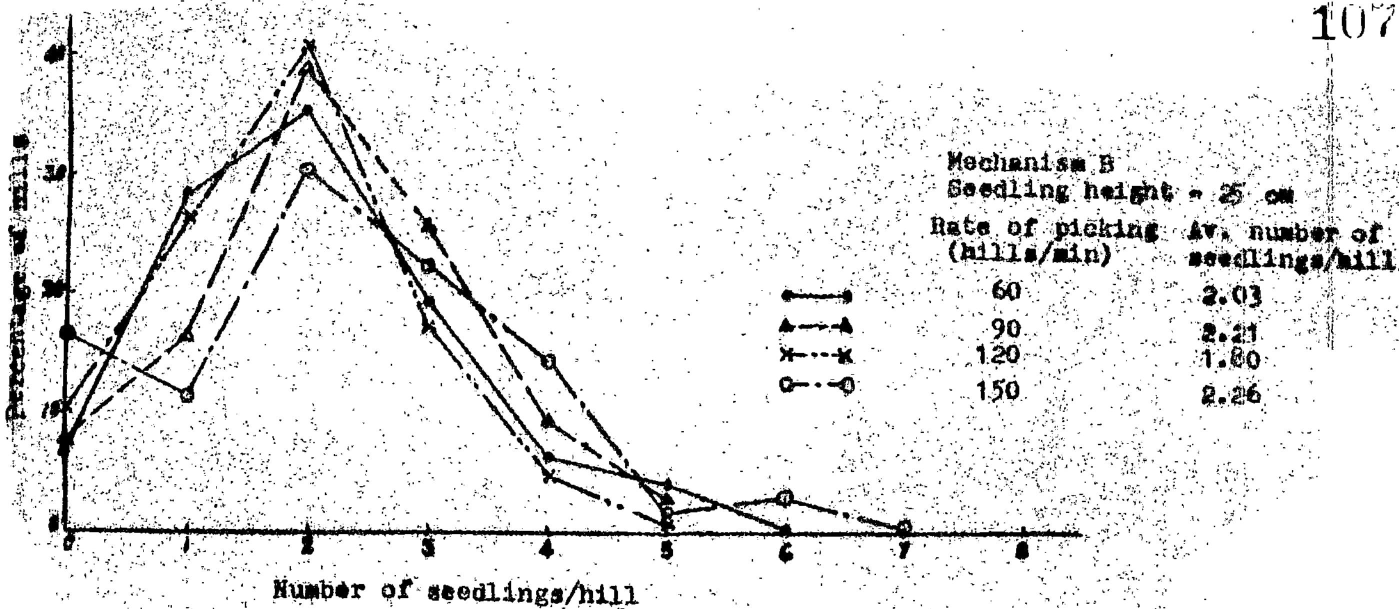


No. of seedlings/hill	0	1	2	3	4	5	6	7	8	Rate of picking
Percentage of seedlings hills	4.8	18.67	29.07	24.0	17.33	6.13				60 hills/min
	5.33	28.27	32.27	16.80	13.87	3.20	0.26			90 hills/min
	6.40	20.53	32.80	22.93	10.13	4.80	2.40			120 hills/min
	16.8	28.53	24.53	14.67	13.33	1.87	0.26			150 hills/min

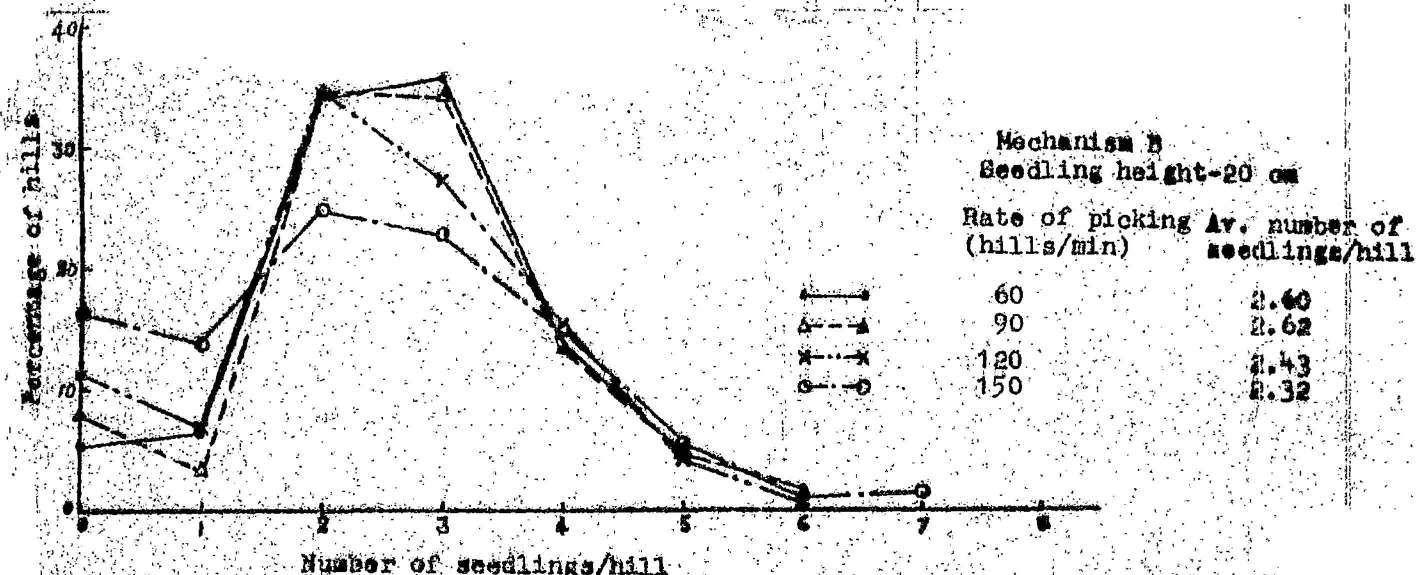


No. of seedlings/hill	0	1	2	3	4	5	6	7	8	Rate of picking
Percentage of seedling hills	5.87	25.6	32.53	18.93	8.00	8.53	0.26	0.26		60 hills/min
	8.00	28.8	30.12	21.33	6.67	4.80	0.27			90 hills/min
	10.67	37.33	33.33	17.07	1.07	0.53				120 hills/min
	16.53	17.87	32.53	20.27	9.87	2.67	0.27			150 hills/min

FIG. 4.8 SEEDLING DISTRIBUTION AT VARIOUS RATES OF PICKING



No. of seedlings/hill	0	1	2	3	4	5	6	7	Rate of picking
Percentage of seedling hills	6.67	20.27	35.20	19.20	6.40	4.00	0.27		60 hills/min
	7.47	16.27	38.67	25.60	9.07	2.93			90 hills/min
	10.40	26.40	40.80	17.33	4.80	0.27			120 hills/min
	16.53	11.20	30.40	22.40	14.40	1.87	2.67	0.53	150 hills/min



No. of seedlings/hill	0	1	2	3	4	5	6	7	Rate of picking
Percentage of seedlings hills	5.33	6.13	34.40	35.73	13.87	4.53			60 hills/min
	8.00	3.20	34.67	34.40	13.60	4.80	1.33		90 hills/min
	11.20	6.93	34.43	27.46	15.47	4.00	0.53		120 hills/min
	16.27	13.60	24.80	22.93	15.20	5.07	0.80	1.33	150 hills/min

FIG. 4.9 SEEDLING DISTRIBUTION AT VARIOUS RATE OF PICKING.

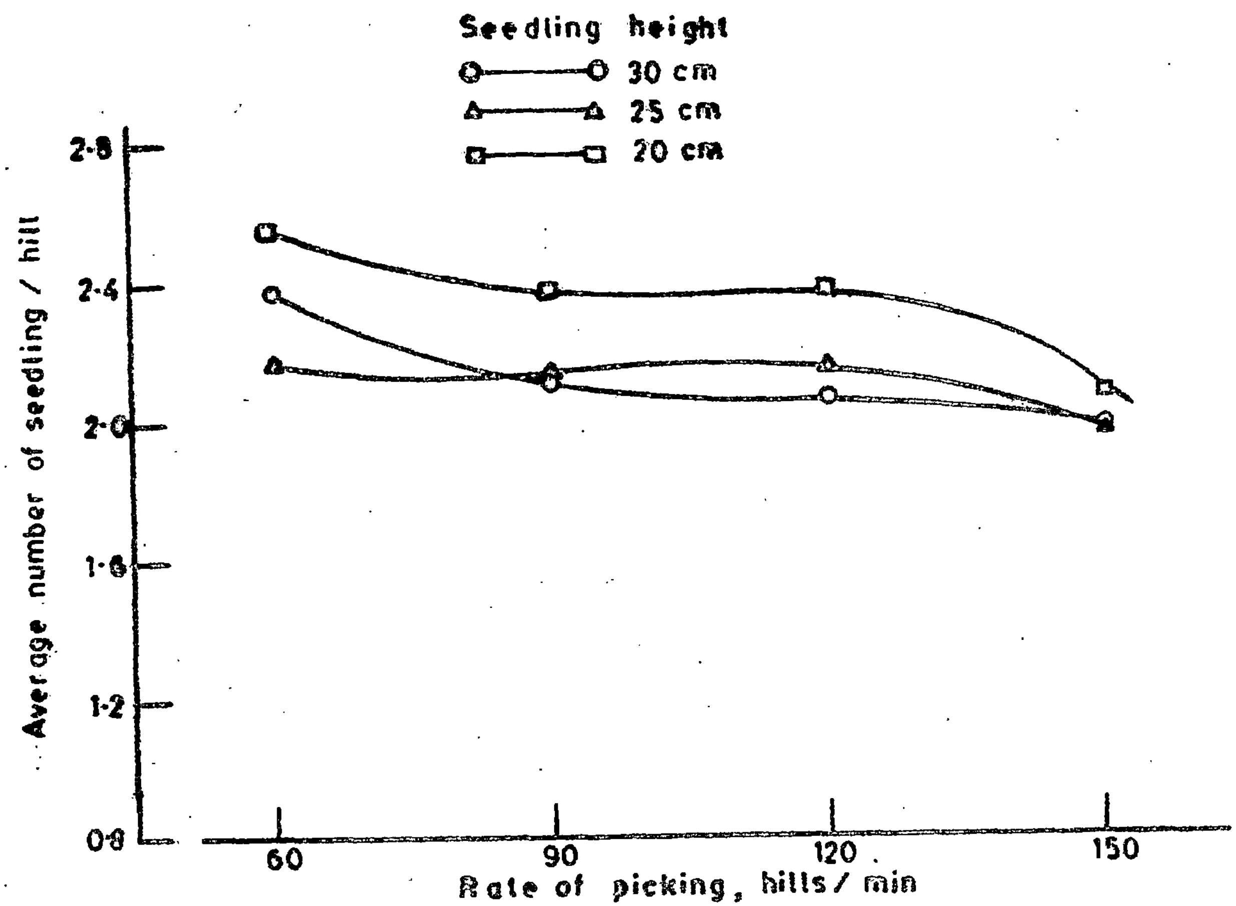


FIG.6.10. EFFECT OF RATE OF PICKING ON AVERAGE NUMBER OF SEEDLINGS/HILL AT VARIOUS SEEDLING HIEGHTS

of variation is shown in Fig. 4.10. It was evident that the average number of seedlings decreased as the rate of picking increased.

4.1.2 Plant hill missing: The data was analysed statistically and presented vide Table 4.2. It was found that the main effect of rate of picking and the first order interaction namely rate of picking x mechanism were both significant at 5 per cent level. The nature of the variation of plant hill missing with the rate of picking is shown in Fig. 4.11. It was found that the minimum plant hill missing was at a rate of picking of 60 hills/min and was 4.09 per cent for mechanism-A and 6.95 per cent for mechanism-B, which increased to 16.8 and 16.44 per cent for mechanism-A. and B respectively at a rate of picking of 150 hills/min. However, within the range of 60 to 120 hills/min, the missing of hills ranged from 4.09 to 5.69 per cent for mechanism-A and 6.95 to 10.76 per cent for mechanism-B, while the mechanism was designed for a plant hill missing of 5 per cent. Though, studies on the permissible limit of missing had shown that as much as 9 per cent missing hills with a maximum consecutive missing hills of 3/sq.m. could be compensated by the neighbouring hills, 5 per cent missing hills was the recommended level (38, 40). Therefore, mechanism-A can be adopted to operate upto a rate of picking of 120 hills/min, as the percentage of missing hills exceeded only by 0.69 per cent, but was well within the maximum permissible limit.

Table 4.2 Analysis of variance for plant hill missing

Source	d.f	S.S.	M.S.S	F_{obs}	F_{tab}
1	2	3	4	5	6
Replications (R)	2	0.0240	0.0120	0.0320	3.20
Rate of picking (P)	3	1454.4000	484.8000	1454.1092*	2.81
Height of seedlings (H)	2	1.1377	0.5689	1.7064	3.20
Mechanisms (M)	1	96.1420	96.1420	288.3758*	4.05
Rate of picking x Height of seedling	6	2.9863	0.4977	1.4928	2.30
Seedling height x Mechanism	2	1.7773	0.8887	2.6656	3.20
Rate of picking x Mechanism	3	67.6180	22.5393	67.6061*	2.81
Picking rate x seed-ling height x mechanism	6	3.2097	0.5350	1.5747	2.30
Error	46	15.3360	0.3334	-	-
Total	71	1642.6310			

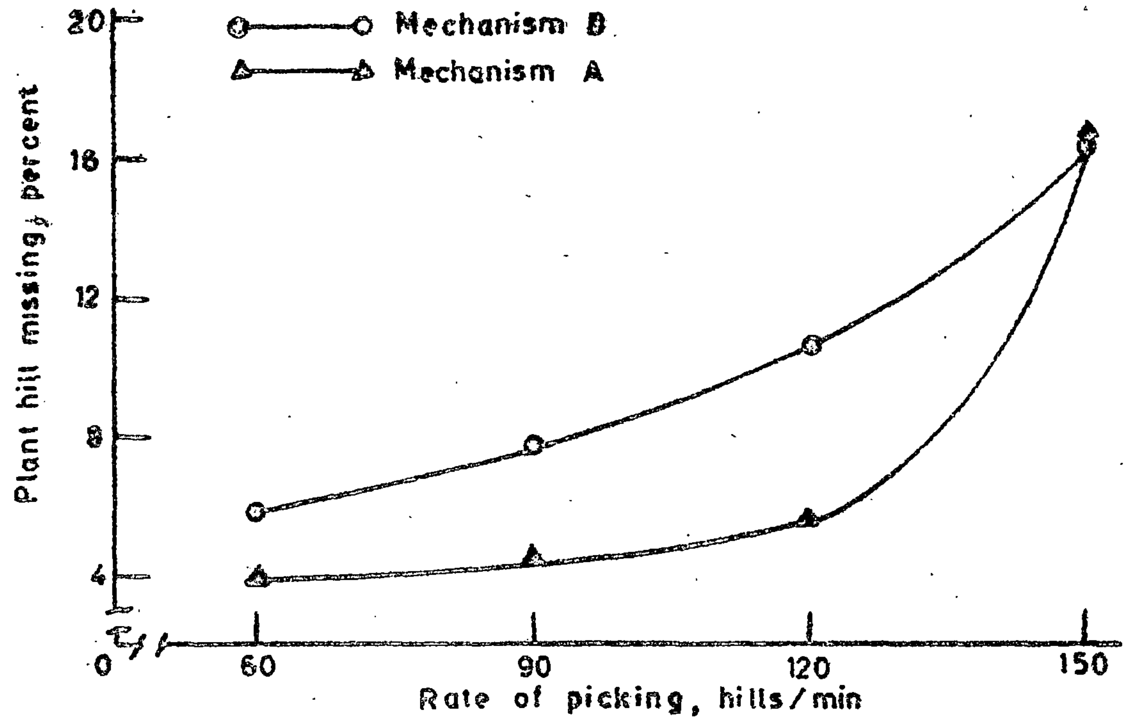


FIG.4.11. EFFECT OF RATE OF PICKING ON PLANT HILL MISSING FOR THE TWO MECHANISMS

4.1.3 Seedling damage: The data were analysed statistically and the analysis of variance for seedling damage is presented in Table 4.3. It was found that the rate of picking was significant at 5 per cent level, with respect to seedling damage. All the interactions of first and second order were non-significant at 5 per cent level. The critical difference at 5 per cent level was computed and compared with the treatment mean differences. This showed that the differences between 150 and 60, 90 and 120 hills/min were significant at 5 per cent level.

The variation in seedling damage with rate of picking is shown in Fig. 4.12. The seedling damage ranged from 0.71 to 1.42 per cent for mechanism-A and 0.53 to 0.88 per cent for mechanism-B, at rates of picking of 60 to 150 hills/min respectively. However, with in the range of 60 to 120 hills/min of rate of picking, the seedling damage in both the mechanisms did not exceed 0.8 per cent as against the designed value of 1.0 per cent. It was reported that 11 to 42.3 per cent of the damaged seedlings sustained the injuries caused by the transplanting machines in Japan (51). The exact percentage of damaged seedlings could, therefore, be assessed only after verifying it through actual transplanting in the field. The injuries caused in these mechanisms can be attributed to the higher tip velocity of the pickers.

Table 4.3 Analysis of variance for seedling damage

Source	d.f	S.S.	M.S.S	F_{obs}	F_{tab}
1	2	3	4	5	6
Replication (R)	2	0.6578	0.3289	1.8222	3.20
Rate of picking (P)	3	2.7378	0.9126	5.0560*	2.81
Height of seedling(H)	2	0.2312	0.1156	0.6404	3.20
Mechanisms (M)	1	0.8889	0.8889	4.9247*	4.05
Rate of picking x Height of seedling	6	1.2622	0.2104	1.1657	2.30
Seedling height x Mechanism	2	0.8711	0.4356	2.4133	3.20
Rate of picking x Mechanism	3	0.7467	0.2489	1.3789	2.81
Rate of picking x Height x Mechanism	6	2.1866	0.3644	2.0188	2.30
Error	46	8.3022	0.1805	-	-
Total	71	17.8845			

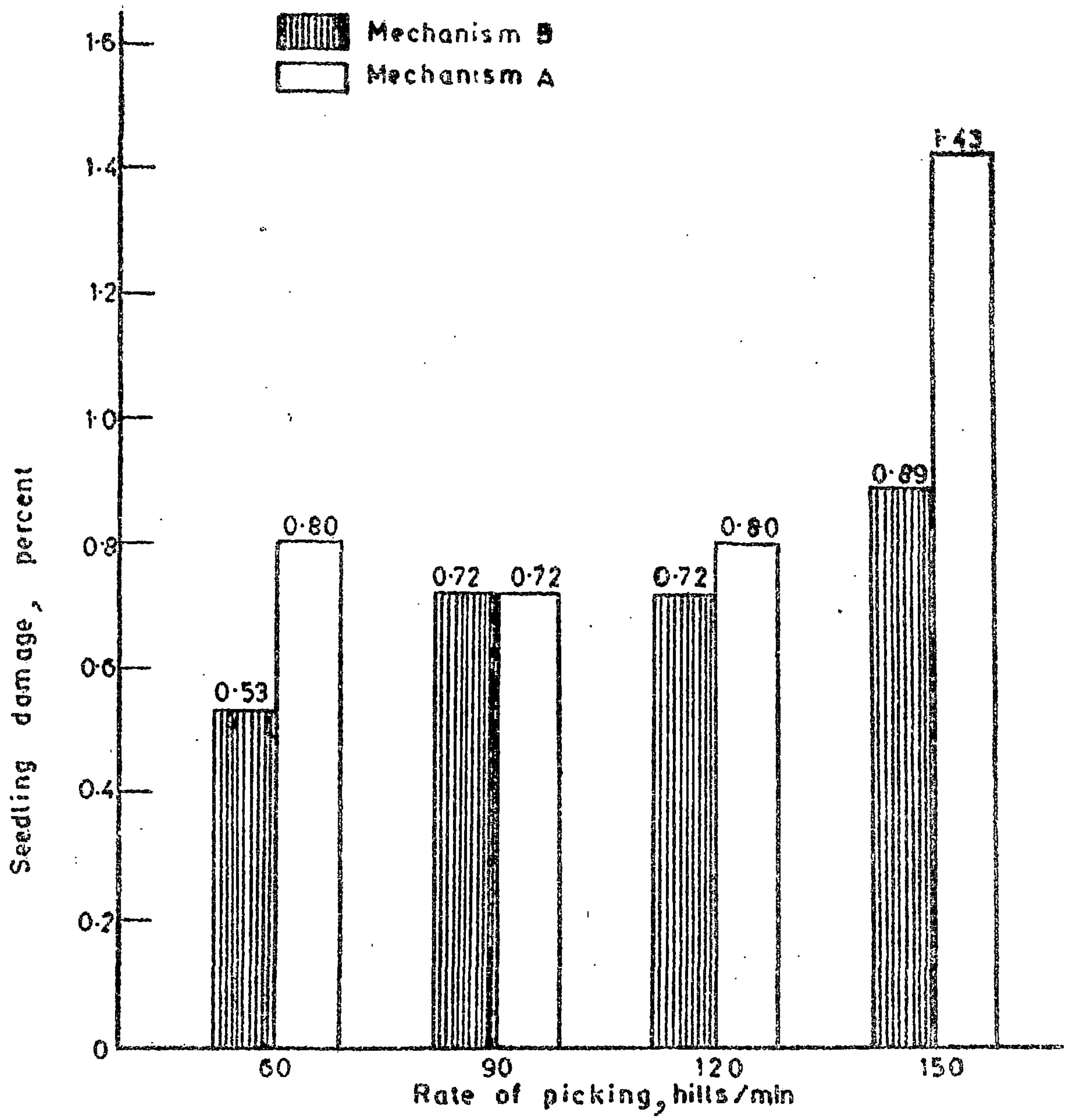


FIG.4.12 EFFECT OF RATE OF PICKING ON SEEDLING DAMAGE FOR THE TWO MECHANISMS

4.1.4 Power consumption: The power consumption was found to vary with the rate of picking with a correlation coefficient of 0.999. The equations connected the power consumption, Y and the rate of picking, X were Y = 0.2244 X and Y = 0.2824 X for mechanism-A and B respectively. The variation of power consumption with the rate of picking is shown in Fig. 4.13. The linear increase in power consumption with rate of picking can be attributed to the work done which is proportional to the rate of picking.

4.2 Effect of Height of Seedling

The effect of 3 levels of seedling height was studied for the following indices:

4.2.1 Seedling hill distribution: The percentage of hills with 0, 1, 2 to 4 and 5 to 8 seedling in each hill, were tabulated and the results are represented in Fig. 4.1 through 4.9. The average number of seedlings/hill was computed and Fig. 4.10 shows the effect of seedling height on average number of seedlings/hill. The results were statistically analysed and the analysis of variance for the average number of seedlings/hill is presented in Table 4.1. It was found that the main effect of the seedling height and the first order interactions, viz., seedling height x rate of picking, seedling height x mechanism, as well as second order interaction viz., seedling height x rate of picking x mechanism were all significant at 5 per cent

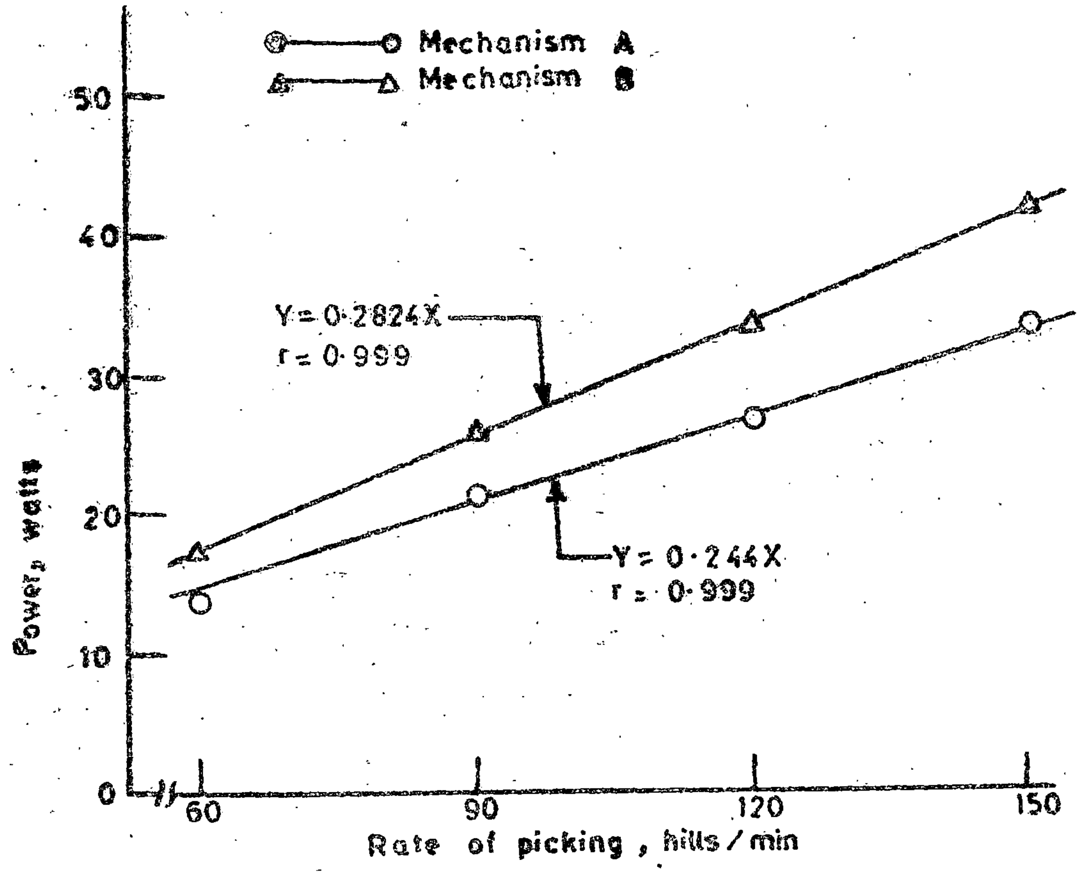


FIG.4.13. EFFECT OF RATE OF PICKING ON POWER CONSUMPTION FOR THE TWO MECHANISMS

level. The critical difference was computed and compared with the treatment mean differences. This indicated that at the rate of 60 hills/min all the seedling heights were significantly different at 5 per cent level. At 90 hills/min, seedling heights 30 and 20 cm, as well as seedling heights 25 and 20 cm were significantly different. At 120 hills/min, all the seedlings heights were significantly different, whereas seedling heights 30 and 25 cm were not significantly different at 5 per cent level at 150 hills/min. This meant that as the height of the seedlings was reduced to 20 cm, the number of seedlings/hill was affected and the effect was to pick up a higher number of seedlings/hill. This was because, as the length of seedling was reduced, it could be moved to the opening of the seedling box as well as pushed down by the ejector easily and enabled the pickers to grip better.

4.2.2 Plant hill missing: The data was analysed statistically for plant hill missing and the analysis of variance is shown in Table 4.2. It was found that the seedling height had no significant effect on the plant hill missing at 5 per cent level. All the first and second order interactions were also non-significant at 5 per cent level. This showed that seedlings of any height between 20 and 30 cm could be used without remarkable change in plant hill missing.

4.2.3 Seedling damage: The statistical analysis of the data was done and the analysis of variance for seedling damage is shown in Table 4.3. It was found that the main effect as well as interactions of the seedling height were not significant with respect to the seedling damage at 5 per cent level. Thus, it could be infered that the seedlings of any height between 20 and 30 cm could be used without appreciable change in seedling damage.

4.2.4 Power consumption: The observations for power consumption for the transplanting mechanisms-A and B, showed that, the power consumption was not affected by the change in seedling height and as such seedlings of 20 to 30 cm height could be used without any change in power consumption.

4.3 Effect of the Mechanism

The effect of the tip velocity of the pickers for the mechanism-A with two sets of pickers and mechanism-B with four sets of pickers were studied to evaluate their performance on the following indices, namely; seedling distribution, seedling damage, plant hill missing and power consumption.

4.3.1 Seedling distribution: The percentage of hills with 0, 1, 2 to 4 and 5 to 8 seedlings in each hill was computed and tabulated. The results are represented in Figs. 4.1 through 4.9. The data were analysed statistically for the average number of seedlings/hill. The analysis of variance is shown in Table 4.1. It was found that the main effect of the two mechanisms was non-significant at 5 per cent level, while the first order interactions namely; seedling height x mechanism, rate of picking x mechanism as well as the second order interaction, seedling height x rate of picking x mechanism were all significant at 5 per cent level. This is because, basically both the mechanisms are the same and so the seedling distribution was not significantly affected. However, the combined effect of mechanism, rate of picking and seedling height was significant and it is difficult to attribute the reason for the interactions.

4.3.2 Plant hill missing: The statistical analysis of the data and the consequent analysis of variance, for plant hill missing, presented in Table 4.2, showed that the main effect of the two mechanisms, and the first order interaction i.e. rate of picking x mechanism were both significant at 5 per cent level. The critical difference was computed and compared with the treatment mean difference, which had shown that the two mechanisms were significantly different at 5 per cent level, with respect to plant hill missing.

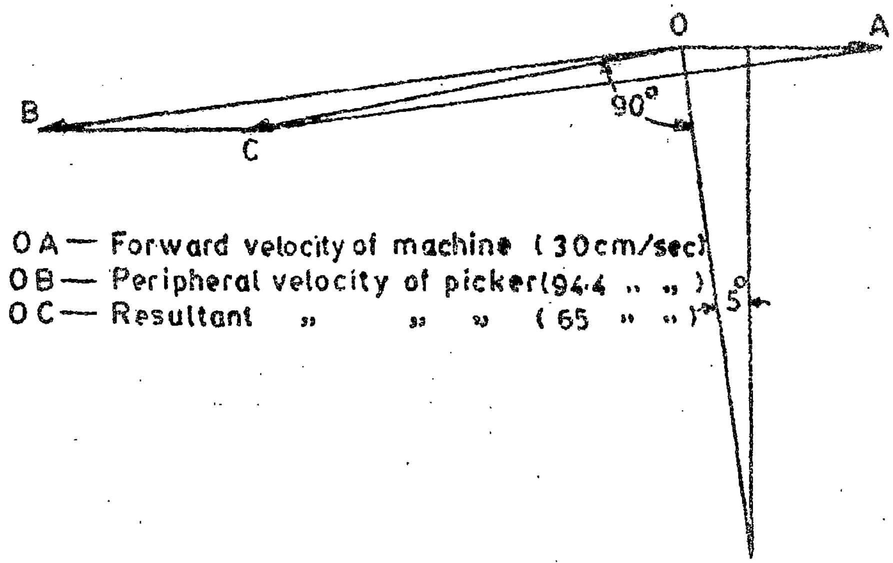
The effect of the mechanisms on plant hill missing is represented in Fig. 4.11. It was evident that regarding plant hill missing, mechanism-A was superior to mechanism-B, at all picking rates studied. The plant hill missing ranged from 4.09 to 16.8 per cent for mechanism-A and from 6.95 to 16.44 per cent for mechanism-B, when rate of picking varied from 60 to 150 hills/min, but at a rate of picking of 120 hills/min, the missing of plant hills was 5.69 and 10.76 per cent for mechanism-A and B respectively, as against the required 5 per cent. It is, therefore, evident that mechanism-A is adoptable upto a speed of 120 hills/min, as the plant hill missing exceeded only 0.69 per cent.

The increase in plant hill missing in mechanism-B could be attributed to the geomtry of the mechanism. The locus of the picker-tip of the mechanism-B was a circle of 47 cm diameter, while that of mechanism-A was a circle of 30 cm diameter but the other components like seedling box, seedling rake, seedling ejector, were of the same specifications in both mechanisms. This showed that the picker-tip of mechanism-B travelled a longer distance and remained for more time in seedling box, than for mechanism-A. This offered an obstruction to the seedling movement and led to higher plant hill missing.

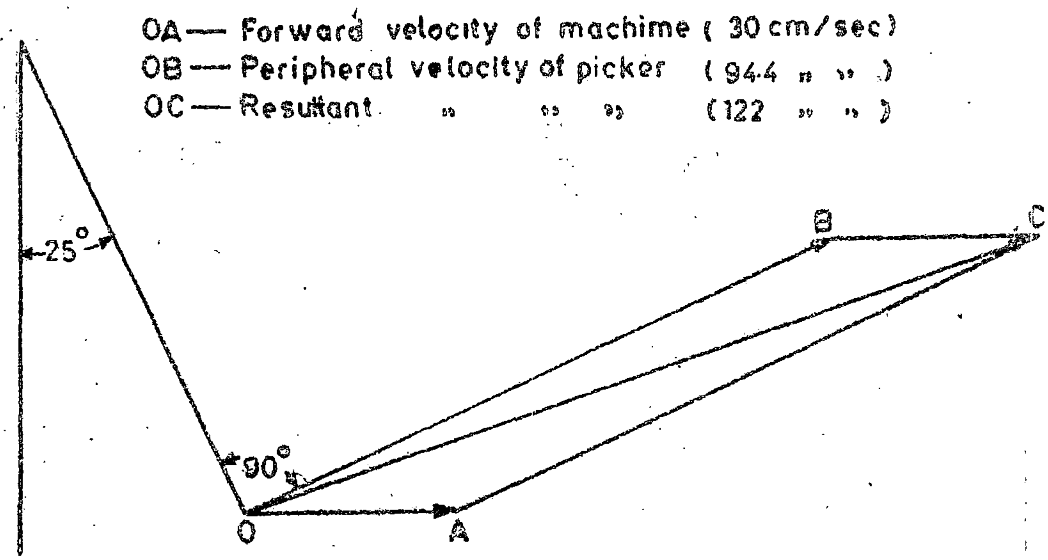
4.3.3 Seedling damage: The data were analysed statistically and the analysis of variance is presented in Table 4.3. It was found that the seedling damage was significantly different in the two transplanting mechanisms, at 5 per cent level. All the first and second order interactions were not significant at 5 per cent level. The effect of the mechanism on seedling damage is shown in Fig. 4.12. The critical difference was computed and compared with treatment means, which showed that there was no significant difference at 90 and 120 hills/min, while the damage was significantly different at other rates. It was evident that the seedlings damage was more for mechanism-A than for mechanism-B except at the rate of picking of 90 hills/min. Though the maximum seedling damage was 1.4 per cent at the rate of picking of 150 hills/min for mechanism-A, in the range of 60 to 120 hills/min, the seedling damage in both the mechanisms did not exceed 0.8 per cent as against the designed maximum limit of 1 per cent.

The higher percentage of seedling damage in mechanism-A could be attributed to following reasons:

1. The velocity of the picker-tip of mechanism-A was more than that of mechanism-B (Figs. 4.14 and 4.15) and this increased the scratching and rubbing of the scraper of the fixed picker with seedlings.
2. As the picker of the mechanism-B travelled a longer distance in side the seedling box at a lower speed, it did not hurt the seedlings much.



VELOCITY DIAGRAM AT THE POINT OF PICKING



VELOCITY DIAGRAM AT THE POINT OF RELEASE

FIG.4.14. VELOCITY DIAGRAMS FOR MECHANISM – A AT A RATE OF PICKING 120 HILLS/min

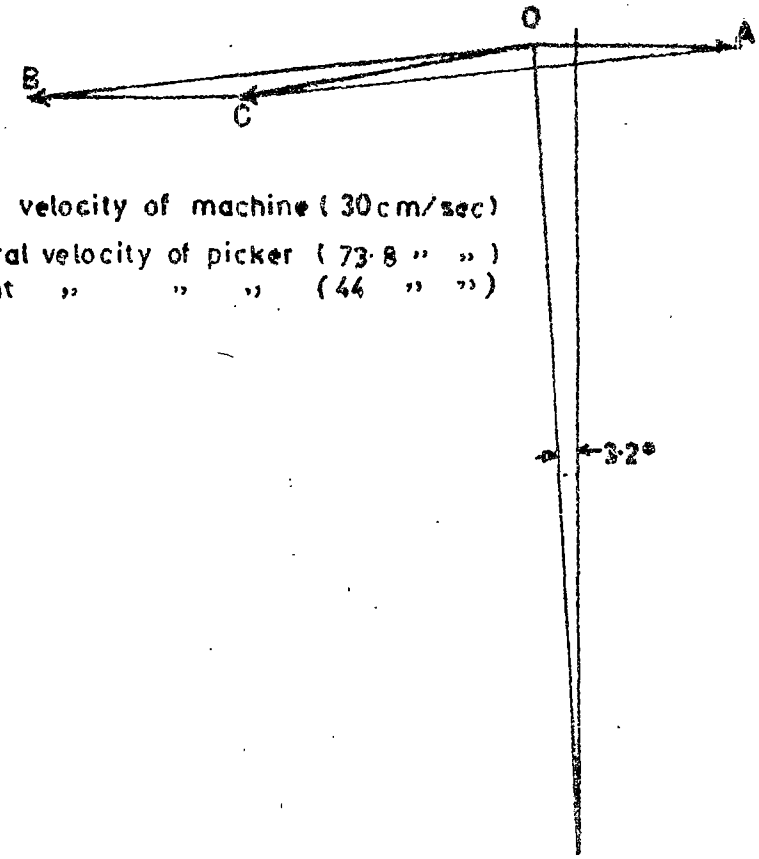


FIG.4.15 VELOCITY DIAGRAM AT THE POINT OF PICKING FOR MECHANISM – B AT A RATE OF PICKING 120 HILLS/min

3. As the length of the pickers of mechanism-A was less than that of mechanism-B, the angle between the picker-tip velocity and seedlings was more in the case of mechanism-A, than in mechanism-B. This caused bending of the seedlings and thus damaged them.

4.3.4 Power consumption: The power consumption at various rates of picking for the two mechanisms was computed and it was found that the mechanism-B consumed more power than mechanism-A. At the lowest rate of picking it was 13.58 and 17.07 watts for mechanism-A and B respectively. It varied linearly in both the cases with a correlation coefficient of 0.999, and a slope of 0.2244 and 0.2824 for mechanisms-A and B respectively.

The power consumed was to overcome the friction at the bearings and cams and also to open the pickers against the spring force. The higher power requirements of mechanism-B could, therefore, be attributed to the higher spring force and larger frictional torque.

The comparison of various treatment means with their critical differences and the table of means and standard deviations of the performance indices are given in Appendices-H and I.

The various performance indices are plotted against the tip velocity of the pickers also, and shown in Fig. 4.16.

The laboratory testing of the transplanting mechanism-A, in the movable soil bin filled with puddled soil, had shown that the mechanism could not plant the seedlings perfectly erect. Out of fifteen observations, the angle of planting ranged from 9° to 46° with a mean of 27.22°. The depth of planting also varied from 1.0 to 4.1 cm with a mean of 2.68 cm in these observations, as against the required 3 to 4 cm depth. However, as the mechanism and soil bin were separately driven, there was no synchronisation between the forward movement of the bin and the rotary speed of the mechanism, and hence did not provide a perfect simulation of the ground-wheel driven mechanism, but it did help to provide a visual indication of the functionability of the planting system.

The transplanting mechanism-A was fitted with a ground-wheel and subjected to a limited preliminary trials in the actual field. These trials revealed the following points:

1. It could pick and release the seedlings without fail, but could not plant them in the upright posture properly. The seedlings remained lying almost horizontal, with their roots slightly dipped in the puddled soil.

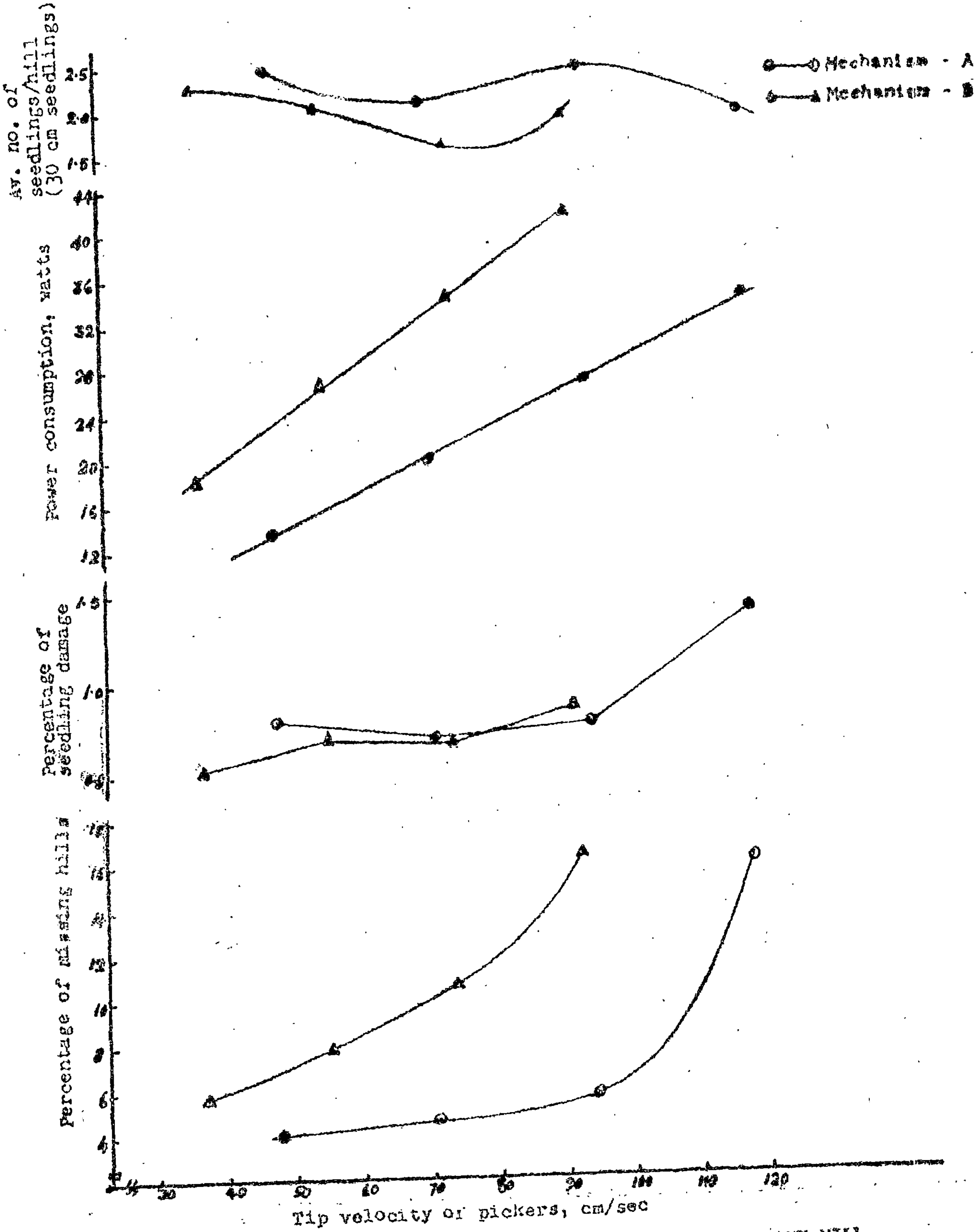


FIG. 4.16 EFFECT OF TIP VELOCITY OF PICKERS ON PLANT HILL MISSING, SEEDLING DAMAGE, POWER CONSUMPTION AND AVERAGE NUMBER OF SEEDLINGS/HILL

2. After covering a distance of 3 to 4 m of forward travel, the mud got deposited on to the cam of the seedling ejector and picker assembly, which hampered with their proper functioning and offered considerable resistance to their movement. This led to the skidding of the ground wheel.

3. The planting finger, moved by the pickers, carried a good amount of mud and threw forward which struck to the tip of the pickers.

4. The hinge of the planting finger did not function properly due to the mud sticking to the hinge-point. Thus the planting finger acted as a straight piece in effect, which led to the throwing of more and more mud as the finger passed under the puddled soil surface.

In order to reduce the hazard of sticking mud, it was tested in a puddled field with standing water of 3 to 4 cm depth. This led to reduction in the mud-sticking tendency on various parts, but could not eliminate the problem entirely. Measurements relating to actual planting could not be taken due to the improper functioning of the mechanism in the field. However, the picking and releasing system worked quite satisfactorily; the planting system and the ground-wheel drive will, therefore, be improved further.

The mechanism could not plant the seedlings erect, because, at the time of release, the seedlings were inclined to the horizontal at an angle of about 25° with their leaves touching the puddled loose soil (Fig. 4.17). This prevented them from being planted erect, even when the planting finger pressed at the roots.

As a comparison with the commercial models of transplanting machines, this newly developed mechanism had a reasonal rate of picking of 120 hills/min, as against 100 and 120 hills/min of most of the Japanese transplanters using conventional seedlings (46). The plant hill missing at this rate was 5.69 per cent for mechanism-A, while most of the transplanters had shown as much as 12.5 per cent missing (36, 38, 58). The test reports of three commercial machines, for the accuracy of planting, showed 5.6 to 22.1 per cent of floating seedlings and 36.8 to 72.7 per cent leaning seedlings (36).

It was found that on an average 7.5 minutes of time was required for washing and loading one box of seedlings for the newly developed mechanisms, which could be planted in 10 sq.m. of area, and this amounted to 125 man-hrs/ha. If a 4-row bullock-drawn version was used the transplanting time would be about 12 hrs/ha, which could substantially reduce the labour.

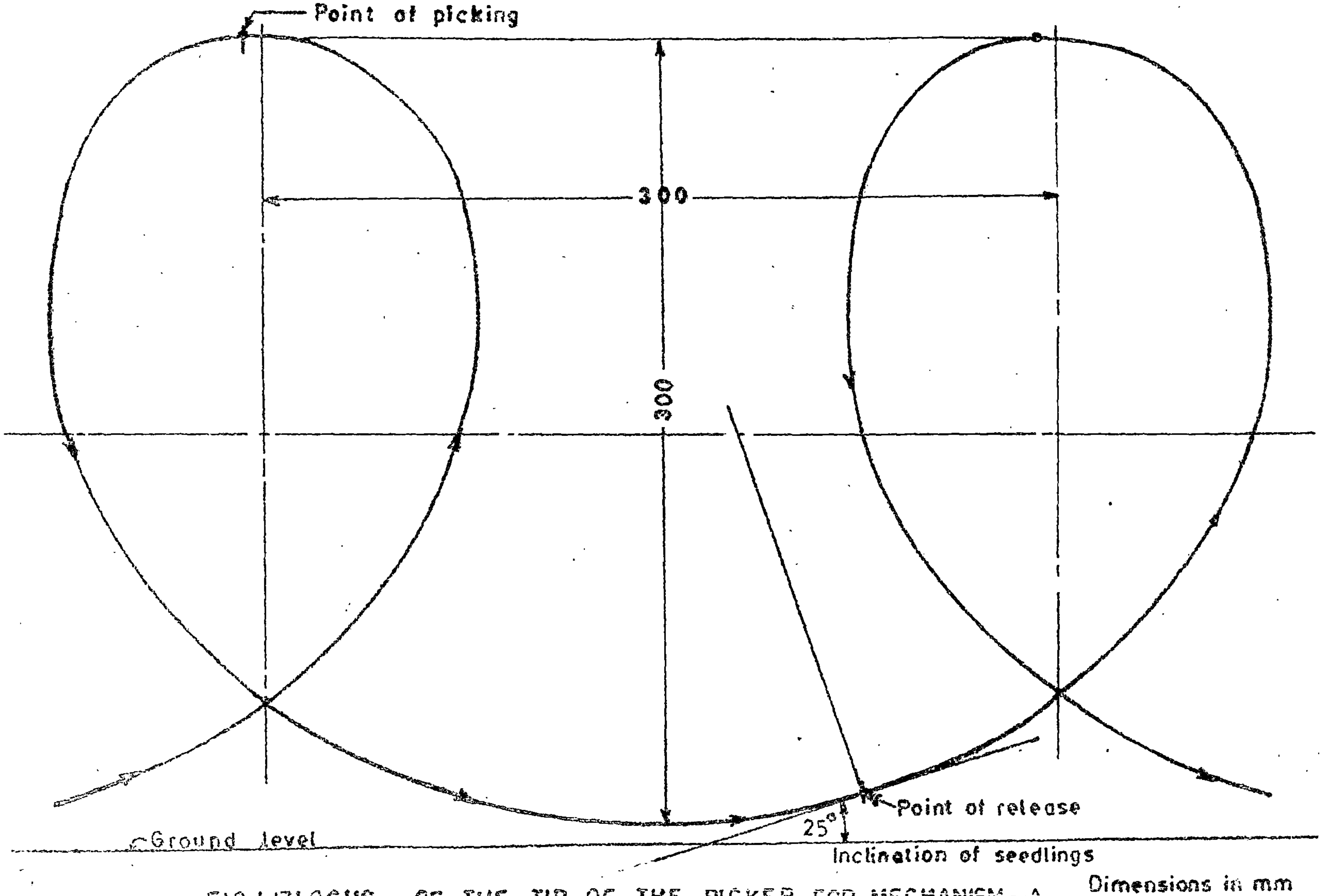


FIG.4.17 LOCUS OF THE TIP OF THE PICKER FOR MECHANISM – A

Chapter V

SUMMARY AND CONCLUSIONS

For over half of the world's population, rice provides the main dietary source of energy and hence is one of the most important food materials. In the Far-East, where 90 per cent of world's rice is grown, transplanting is widely practised due to numerous advantages offered by this method. Manual transplanting being a rather tedious operation, paddy transplanters had been developed and introduced in several countries notably Japan. Transplanters using conventional seedlings, however, are still receiving world wide attention as the commercial transplanters such as in use in Japan were costlier and employed special type of nursery raised with much care and skill. It was, therefore, decided to develop and test a new type of paddy transplanting mechanism, with the following specific objectives:

1. To design and develop a mechanism for transplanting conventional paddy seedlings
2. To test the transplanting mechanism under laboratory conditions
3. To identify the important parameters of the mechanism and establish their range for optimal operation of the unit designed under objective (1).

Accordingly, a paddy transplanting mechanism was designed and developed. Attempts were made to overcome, as far as possible, the drawbacks of similar mechanisms already developed and reported. It was a single-row unit with provision to add more such units, so as to make a multi-row machine with a row-spacing of 20 cm. It was designed to transplant washed-root seedlings of 20 to 30 cm length at a hill to hill distance of 15 cm, with 2 to 3 seedlings/hill, to a depth of 3 to 4 cm, with not more than 5 per cent missing hills and 1 per cent seedling damage. Made mainly of M.S. and supported on a wooden float, the mechanism weighed 9.5 kg without seedlings. The important components of the mechanism were a seedling box to hold the seedlings, a seedling rake and seedling ejector for positive conveyance of the seedlings into the picker-jaws, a pair of picker sets mounted on the main shaft and actuated by a stationary cam to pick and release the seedlings, and a planting finger to plant the seedlings, laid horizontally on the ground after release, by the pickers. The main shaft was rotated by a ground wheel, as the mechanism was drawn forward by manual, animal or tractor power.

In order to study the effect of reduced tip velocity of the pickers, another mechanism with four picker-sets, based on the same concept as the first one, but with proportionately larger dimensions of pickers and stationary cam, was also fabricated. The components like seedling box, rake, ejector and main shaft were retained with the same specifications as for the mechanism with two picker-sets. This mechanism weighed 11.75 kg against 9.5 kg for the first mechanism. The mechanism with two picker sets was designated as mechanism-A and that with four picker sets as mechanism-B for convenience.

The two mechanisms were tested in the laboratory to compare their performance in respect of the plant hill missing, seedling damage, seedling distribution, average number of seedlings per hill and the power consumption. The tests were conducted with 4 rates of picking, i.e. 60, 90, 120 and 150 hills/min and 3 seedling heights i.e. 30, 25 and 20 cm for both mechanism A and B.

The laboratory tests revealed that as the rate of picking increased from 60 to 150 hills/min, the missing hills increased from 4.09 to 16.8 per cent and 6.95 to 16.44 per cent; seedling damage from 0.8 to 1.43 per cent and 0.53 to 0.89 per cent; and power consumption from 13.6 to 33.6 and 17.1 to 42.1 watts for mechanisms A and B respectively. The average number of seedlings for both the mechanisms studied, decreased from 2.4 to 2.0 for 30 cm long seedlings as the rate of picking increased from 60 to 150 hills/min. However, upto a picking rate of 120 hills/min, the missing hills were 5.69 and 10.69 per cent for mechanisms A and B respectively, as against the desired 5 per cent missing hills. Seedling damage was less than 1 per cent and average number of seedlings/hill was above 2.00 in both the mechanisms with a variation of 0 to 8 seedlings/hill with a maximum standard deviation of 1.32.

As the seedling height was reduced from 30 to 20 cm, the average number of seedlings/hill was found to increase from 2.36 to 2.55 at the rate of picking of 60 hills/min, 2.11 to 2.39 at 90 hills/min, 2.07 to 2.39 at 120 hills/min and 1.99 to 2.09 at 150 hills/min. At all seedling heights, upto 120 hills/min, the average number of seedling/hill was above 2.00, which was within the required limit.

On comparing the performance of the two mechanisms, it was found that there was no difference between the two regarding their ability to pick the number of seedlings/hill. However, missing hills were more in mechanism B as compared to mechanism A. For a rate of picking, upto 120 hills/min mechanism A had acceptable missing hill of 5.69 per cent as against the recommended 5 per cent, while mechanism B, had 10.67 per cent which was considerably higher than the acceptable limit. The seedling damage, upto 120 hills/min rate of picking was under 1 per cent for both the mechanisms.

Limited field trials revealed that the planting finger provided in the mechanism did not function satisfactorily and as such the plants were not properly planted. Deposition of mud on the stationary cam and seedling ejector was a problem noticed in the field. Consequently, the free rotation of the main shaft was hampered which in turn led to the skidding of the ground wheel. This called for further improvements in the design of the planting finger and ground-wheel drive.

It was concluded that mechanism A could pick the seedlings from the seedling box and release them satisfactorily on the ground upto a picking rate of 120 hills/min. The missing hills and seedling damage were within acceptable limits. Trouble-free working of the transplanter fitted with such mechanism would have a capacity of about 0.0216 ha/hr per row. The forward speed for the rate of picking viz. 120 hills/min comes to about 1.08 kmph. The mechanism could not plant the seedlings erect and improvement on planting finger was needed. About 125 man-hrs/ha were required to wash and load the seedlings and if a 4-row bullock drawn version could be used, it would require about 140 man-hrs/ha as against 200 to 250 man-hrs/ha in hand transplanting. This would justify further developmental efforts and refinement of the mechanism.

SUGGESTIONS FOR FUTURE WORK

1. An improved arrangement for seedling planting should be developed and incorporated.

2. It may be worth while to improvise the power transmission system of the existing mechanism. The gears if possible should be eliminated.

3. An improved and effective ground-wheel drive should be designed and incorporated.

4. A proto-type with 4 to 6 rows using units similar to the one developed in this investigation should be fabricated and tested in the field.

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Appendix- A

DEFINITIONS OF TERMS

1. Conventional seedlings: These are seedlings pulled up from atraditional nursery field. After pulling up, the roots are washed of the soil and separated from each other.

2. Unconventional seedlings: These are seedlings which are raised under controlled conditions in seedling boxes, trays or special nursery fields. Seedlings grown by this method will have their roots inter-woven with the nursery bed material inbetween, to form a seedling mat or band.

3. Plant hill: This refers to the group of seedlings picked and released in one stroke of a picker set.

4. Plant hill missing: This refers to the non-picking or total absence of a particular hill (expressed in percentage of total strokes performed).

5. Plant hill density: This refers to the number of plant hills per unit area of the transplanted field (number of hills/sq.m.).

6. Hill to hill distance: This is the distance between two consecutive hills in a row (cm).

7. Row to row distance or row spacing: This is the distance between two adjacent rows (cm).

8. Field capacity: This refers to the area covered by the transplanter in unit time (ha/hr).

9. Rate of picking (P): This is the number of hills picked from the seedling box in unit time (hills/min).

10. Seedling height (H): This is the total length of the seedling stem including leaves. This excludes the length of roots (cm).

11. Damaged seedlings: These are seedlings found damaged by scratching, splitting, or bending due to mechanical picking and dragging by the pickers, distinguished visually, as shown in Fig. 3.18 (expressed as a percentage of the total seedlings released).

12. Average number of seedlings/hill: This is the total number of seedlings released in hills divided by the total number of picker-strokes performed (seedlings/hill).

13. Angle of planting: This is the angle between the seedling stem and horizontal (degrees).

14. Depth of planting: This is the vertical depth of the lowest end of the seedling stem from the field surface (cm).

15. Tip velocity of the pickers: This is the tangential velocity of the outer most point of the rotating picker (cm/sec).

16. Forward velocity of the mechanism: It is the linear distance moved by the mechanism per unit-time (kmph).

17. Mechanism-A(M_A): The transplanting mechanism developed under this project, having two picker sets.

18. Mechanism-B (M_B): The transplanting mechanism developed under the project, having four picker sets.

Appendix-B

SPECIFICATIONS OF THE VARIABLE SPEED DRIVE AND INSTRUMENTS USED IN THE LABORATORY TEST

1. Variable speed drive

Electric motor:

Make	:	Crompton Parkinson, India
Frame No	:	B 92 - 6 KM
Speed	:	960 rpm
Output	:	20 hp
Input supply	:	3 phase, a.c., 400/440 v, 50 cps
Current	:	27 A @ Delta

Starter:

Make	:	Siemens India
Type	:	Push button automatic star-Delta
		No: LBO/K 987-SP-2a
		Bi-relay: 12-24 A
		Rating - 25 kw, 415 v, 3 phase 50 cps

Floating centre-vari speed:

Maximum pulley diameter - 18 cm

Minimum pulley diameter - 6 cm

Maximum speed ratio - 1:9

Gear box:

Type : Hand shift with 5 forward and 1 reverse speeds

Gear Ratios :

Gear-	I	II	III	IV	V	R
Input-	6	3.5	1.83	1	0.83	6
Output-	1	1	1	1	1	1

Speed range available at output shaft corresponding to motor speed of 960 rpm } 15 to 1075 rpm

2. Instruments used

Tachometer:

Make : 'VENTURE' Smith Industries, London

Type : Hand Tachometer, Indicating

Range : 0-400 rev/min-Green dial
0-2000 rev/min - Blue dial
0-10,000 rev/min - Red dial

Stop Watch:

Make : RACER, Switzerland

Range : 0 - 30 sec/rev. of centre hand

Energy Meter:

Make	:	Jaipur Electricals Ltd, India
Type	:	Rotating disc, recording type, 3 phase, 4 wire No: K 34
Rating	:	240 v/phase, 30 A /phase 50 cps.
Constant	:	60 revolution/kwh

Appendix- C

CHARACTERISTICS OF THE SEEDLINGS

Variety	:	PR 106, Medium
Date of sowing Nurseries	:	20-6-1979 and 25-6-1979
Date of Testing	:	25th, 26th, 27th and 28th July, 1979 and 1st, 2nd, 3rd and 4th August, 1979
Age of seedling and leaf stage	:	35 to 40 days 5 to 6 leaf stage
Height of seedlings	:	28 to 32 cm

Appendix-D

STATISTICAL LAYOUT OF THE EXPERIMENT

Statistical layout of the experiment	:	4 x 3 x 2 Factorial with 3 replications in Randomized Block Design

Factors:

1. Rate of picking (P) : 4 levels:

   P_1 = 60 hills/min

   P_2 = 90 hills/min

   P_3 = 120 hills/min

   P_4 = 150 hills/min

2. Seedling height (H) : 3 levels:

   H_1 = 30 cm

   H_2 = 25 cm

   H_3 = 20 cm

3. Mechanisms (M) : 2 levels:

   M_A = with 2 picker sets

   M_B = with 4 picker sets

4. Replications (R) : 3; R_1, R_2, R_3

Table D.1 Observations of the laboratory test (R_1)

			Number of seedlings/hill 0	1	2	3	4	5	6	7	8	No. of damaged seedlings	Total hills	Av. number of seedlings/hill	S.D.
			1	2	3	4	5	6	7	8	9	10	11	12	13
			Number of hills												
M_A	P_1	H_1	5	22	34	28	29	7				4	125	2.60	1.28
		H_2	4	26	52	23	11	7	1		1	2	125	2.16	1.19
		H_3	6	20	33	30	26	10				2	125	2.64	1.32
	P_2	H_1	6	26	47	22	17	6	1			3	125	2.32	1.26
		H_2	7	33	42	34	6	3				1	125	2.06	1.08
		H_3	6	24	49	19	20	6	1			3	125	2.36	1.27
	P_3	H_1	7	25	40	27	18	7	1			2	125	2.39	1.30
		H_2	7	17	43	27	20	9	2			1	125	2.57	1.34
		H_3	8	21	45	27	15	6	3			4	125	2.4	1.33
	P_4	H_1	22	25	34	16	22	6				3	125	2.02	1.39
		H_2	20	36	43	19	3	4				2	125	1.69	1.17
		H_3	21	35	30	23	14	2				4	125	1.84	1.31

Table D.1 contd...

			1	2	3	4	5	6	7	8	9	10	11	12	13
M_B	P_1	H_1	7	28	45	24	8	13				1	125	2.30	1.32
		H_2	8	39	41	24	8	5				2	125	2.00	1.17
		H_3	7	8	41	44	19	6				2	125	2.62	1.14
	P_2	H_1	9	33	46	26	8	3				1	125	2.00	1.11
		H_2	10	32	39	28	11	5				3	125	2.10	1.23
		H_3	10	0	43	46	22	4				2	125	2.66	1.12
	P_3	H_1	13	46	41	22	2	1				1	125	1.66	0.99
		H_2	13	87	63	18	4	2				2	125	1.70	0.95
		H_3	14	8	50	30	18	5				2	125	2.36	1.25
	P_4	H_1	20	20	40	35	7	3				3	125	1.98	1.23
		H_2	21	12	44	24	19	2	3			3	125	2.21	1.43
		H_3	20	16	33	29	18	6	2	1		2	125	2.32	1.54

Table D.2 Observations of the laboratory test (R_2)

			No. of seedlings/hill									No. of damaged seedlings	Total hills	Av. number of seedlings/hill	S.D.
			0	1	2	3	4	5	6	7	8				
			1	2	3	4	5	6	7	8	9	10	11	12	13
			Number of hills												
M_A	P_1	H_1	4	25	41	44	13	8				3	125	2.41	1.19
		H_2	5	25	44	29	10	10	1		1	3	125	2.43	1.36
		H_3	6	27	40	26	20	6				2	125	2.36	1.25
	P_2	H_1	6	38	38	28	10	5				4	125	2.10	1.18
		H_2	6	35	42	33	7	2				0	125	2.05	1.05
		H_3	7	38	40	17	20	3				2	125	2.11	1.23
	P_3	H_1	7	22	32	31	18	12	3			1	125	2.63	1.44
		H_2	6	18	46	29	16	8	2			2	125	2.50	1.29
		H_3	8	22	38	34	12	9	2			3	125	2.44	1.34
	P_4	H_1	21	18	39	25	17	5				3	125	2.11	1.38
		H_2	22	40	38	15	8	2				3	125	1.62	1.18
		H_3	20	32	37	13	19	3	1			4	125	1.94	1.40

Table D.2 contd...

			1	2	3	4	5	6	7	8	9	10	11	12	13
M_B	P_1	H_1	8	30	41	27	7	12				2	125	2.25	1.32
		H_2	8	34	45	25	7	5	1			1	125	2.06	1.20
		H_3	7	7	48	46	13	4				1	125	2.50	1.05
	P_2	H_1	11	43	27	30	8	6				1	125	1.99	1.27
		H_2	9	19	55	32	9	1				2	125	2.13	1.02
		H_3	9	7	43	44	13	5	4			3	125	2.61	1.27
	P_3	H_1	14	50	36	23	1	1				0	125	1.60	0.99
		H_2	14	30	50	26	5					2	125	1.82	1.01
		H_3	13	10	34	37	24	7				3	125	2.56	1.32
	P_4	H_1	21	28	35	22	15	3	1			2	125	1.96	1.38
		H_2	21	11	38	28	21	1	5			4	125	2.32	1.51
		H_3	20	15	30	39	21	6	1	2		1	125	2.38	1.57

Table D.3 Observations of the laboratory test (R_3)

			Number of seedlings/hill: 0	1	2	3	4	5	6	7	8	No. of damaged seedlings	Total hills	Av. number of seedlings/hill	S.D.
			1	2	3	4	5	6	7	8	9	10	11	12	13
			Number of hills												
M_A	P_1	H_1	5	26	44	23	16	10	1			3	125	2.42	1.32
		H_2	5	30	38	29	17	5	1			2	125	2.34	1.25
		H_3	6	23	36	34	19	7				1	125	2.46	1.24
	P_2	H_1	7	31	49	27	7	2	2			2	125	2.08	1.14
		H_2	6	36	38	28	12	4	1			1	125	2.16	1.22
		H_3	7	44	32	27	12	3				2	125	2.02	1.18
	P_3	H_1	6	20	36	36	19	8				2	125	2.53	1.24
		H_2	7	27	37	23	19	11			1	2	125	2.47	1.45
		H_3	8	34	40	25	11	3	4			5	125	2.18	1.33
	P_4	H_1	20	29	39	23	13	1				2	125	1.86	1.24
		H_2	21	46	33	13	7	4	1			2	125	1.63	1.27
		H_3	22	40	25	19	17	2				5	125	1.80	1.35

Table D.3 contd...

1			1	2	3	4	5	6	7	8	9	10	11	12	13
M_B	P_1	H_1	7	38	36	20	15	7	1	1		2	125	2.22	1.40
		H_2	9	33	46	23	9	5				1	125	2.04	1.18
		H_3	6	8	40	44	20	7				2	125	2.68	1.14
	P_2	H_1	10	32	40	24	9	9	1			2	125	2.17	1.34
		H_2	9	10	51	36	14	5				2	125	2.41	1.14
		H_3	11	5	44	39	16	9	1			3	125	2.60	1.28
	P_3	H_1	13	44	48	19	1					2	125	1.61	0.89
		H_2	12	32	50	21	9	1				1	125	1.89	1.08
		H_3	15	8	45	36	16	3	2			2	125	2.38	1.29
	P_4	H_1	21	19	47	19	15	4				3	125	1.99	1.33
		H_2	20	19	32	32	14	4	2	2		2	125	2.25	1.54
		H_3	21	20	30	27	18	7		2		2	125	2.26	1.57

Appendix-E

Table E.1 Seedling distribution

			Number of seedlings/hill									Av. no. of seed-lings/hill	Av. no. of damaged seedlings	Percent-tage of damaged seedlin[gs]
			0	1	2	3	4	5	6	7	8			
			1	2	3	4	5	6	7	8	9	10	11	12
						Percentage of hills								
M[illegible]	P_1	H_1	3.73	19.47	31.73	22.67	15.47	6.67	0.26			2.48	3.33	1.07
		H_2	3.73	21.60	35.73	21.60	10.13	5.87	0.80		0.53	2.31	2.33	0.80
		H_3	4.80	18.67	29.07	24.00	17.33	6.13				2.49	1.66	0.53
	P_2	H_1	5.07	25.33	35.74	20.53	9.07	3.47	0.80			2.12	3.00	1.07
		H_2	5.07	27.73	32.57	25.33	6.67	2.40	0.26			2.09	0.67	0.27
		H_3	5.33	28.27	32.27	16.80	13.87	3.20	0.26			2.16	2.33	0.80
	P_3	H_1	5.33	17.87	28.80	25.07	14.67	7.20	1.07			2.51	1.66	0.53
		H_2	5.33	16.53	33.60	21.07	14.67	7.47	1.07			2.51	1.66	0.53
		H_3	6.40	20.53	32.80	22.93	10.13	4.80	2.40			2.34	4.00	1.33
	P_4	H_1	16.80	19.20	29.87	17.07	13.87	3.20				2.00	2.66	1.07
		H_2	16.80	32.53	30.40	12.53	4.80	2.67	0.26			1.65	2.33	1.07
		H_3	16.80	28.53	24.53	14.67	13.33	1.87	0.26			1.86	4.33	1.87

Table E.1 contd...

			1	2	3	4	5	6	7	8	9	10	11	12
M_B	P_1	H_1	5.87	25.60	32.53	18.93	8.00	8.53	0.26	0.26		2.26	1.66	0.53
		H_2	6.67	28.27	35.20	19.20	6.40	4.00	0.26			2.03	1.33	0.53
		H_3	5.33	6.13	34.40	35.73	13.87	4.53	0.26			2.60	1.66	0.53
	P_2	H_1	8.00	28.80	30.13	21.33	6.67	4.80				2.05	1.33	0.53
		H_2	7.47	16.27	38.67	25.60	9.07	2.93				2.21	2.33	0.80
		H_3	8.00	3.20	34.67	34.40	13.60	4.80	1.33			2.62	2.66	0.80
	P_3	H_1	10.67	37.33	33.33	17.07	1.07	0.53				1.62	1.00	0.53
		H_2	10.40	26.40	40.80	17.33	4.80	0.27				1.80	1.66	0.80
		H_3	11.20	6.93	34.43	27.46	15.47	4.00	0.53			2.43	2.33	0.80
	P_4	H_1	16.53	17.87	32.53	20.27	9.87	2.67	0.27			1.98	2.66	1.07
		H_2	16.53	11.20	30.40	22.40	14.40	1.87	2.67	0.53		2.26	3.00	1.07
		H_3	16.27	13.60	24.80	22.93	15.20	5.07	0.80	1.33		2.32	1.66	0.53

Appendix-F

Table F.1 Percentage of hills with 0, 1, 2 to 4 and 5 to 8 seedlings/hill

			Number of seedlings/hill			
			0	1	2 to 4	5 to 8
			1	2	3	4
			Percentage of hills			
M_A	P_1	H_1	3.73	19.47	69.86	6.93
		H_2	3.73	21.60	67.47	7.20
		H_3	4.80	18.67	70.40	6.13
	P_2	H_1	5.07	25.33	62.67	4.27
		H_2	5.07	27.73	64.53	2.67
		H_3	5.33	28.27	62.93	3.47
	P_3	H_1	5.33	17.80	68.53	8.27
		H_2	5.33	16.53	69.33	8.80
		H_3	6.40	20.53	65.87	7.20
	P_4	H_1	16.80	19.20	60.80	3.20
		H_2	16.80	32.53	50.40	2.93
		H_3	16.80	28.53	52.53	2.13
M_B	P_1	H_1	5.86	25.60	59.46	9.07
		H_2	6.67	28.27	68.80	4.27
		H_3	5.33	6.13	84.00	4.50
	P_2	H_1	8.00	28.80	58.13	5.07
		H_2	7.47	16.27	73.33	2.93
		H_3	8.00	3.20	82.67	6.13

Table F.1 contd...

		1	2	3	4
P_3	H_1	10.67	37.33	51.47	0.53
	H_2	10.40	26.40	62.93	0.27
	H_3	11.20	6.93	77.33	4.53
P_4	H_1	16.53	17.87	62.67	2.93
	H_2	16.53	11.20	69.87	5.07
	H_3	16.27	13.60	62.93	7.20

Appendix-G

TWO-WAY TABLES FOR THE 4 x 3 x 2 FACTORIAL EXPERIMENT

Table G.1 Two-way table for average number of seedlings/hill

Between Rate of Picking (P) and Height of Seedling (H)

	Average number of seedlings/hill				Total
	P_1	P_2	P_3	P_4	
	1	2	3	4	5
H_1	14.20	12.66	12.42	11.93	51.21
H_2	13.03	12.91	12.96	11.72	50.62
H_3	15.27	14.36	14.31	12.54	56.48
Total	42.50	39.93	39.69	36.19	158.31

Between Rate of Picking (P) and Mechanisms (M)

	P_1	P_2	P_3	P_4	Total
M_A	21.82	19.26	22.11	16.52	79.71
M_B	20.68	20.67	17.58	19.66	78.59
Total	42.50	39.93	39.69	36.18	158.30

Between Seedling Height (H) and Mechanisms (M)

	H_1	H_2	H_3	Total
M_A	27.49	25.69	26.54	79.72
M_B	23.72	24.94	29.94	78.60
Total	51.21	50.63	56.48	158.32

Table C.2: Two-way table for percentage of plant hill missing

Between Rate of Picking (P) and Seedling Height (H)

	Percentage of plant hill missing				Total
	P_1	P_2	P_3	P_4	
£	1	2	3	4	5
H_1	28.8	39.2	48.0	100.0	216.0
H_2	31.2	37.6	47.2	100.0	216.0
H_3	30.4	40.0	52.8	99.2	222.4
Total	90.4	116.8	148.0	299.2	654.4

Between Rate of Picking (P) and Mechanisms (M)

	P_1	P_2	P_3	P_4	Total
M_A	36.8	46.4	51.2	151.2	285.6
M_B	53.6	70.4	96.8	148.0	368.8
Total	90.4	116.8	148.0	299.2	654.4

Between Height of Seedling (H) and Mechanisms(M)

	H_1	H_2	H_3	Total
M_A	92.8	92.8	100.0	285.6
M_B	123.2	123.2	122.4	368.8
Total	216.0	216.0	222.4	654.4

Table G.3 Two-way table for percentage of seedling damage

Between Rate of Picking (P) and Height of Seedling (H)

	Percentage of seedling damage				Total
	P_1	P_2	P_3	P_4	
	1	2	3	4	5
H_1	4.8	4.8	3.2	6.4	19.2
H_2	4.0	3.2	4.0	7.2	18.4
H_3	3.2	4.8	6.4	7.2	21.6
Total	12.0	12.8	13.6	20.8	59.2

Between Rate of Picking (P) and Mechanisms (M)

M_A	7.2	6.4	7.2	12.8	33.6
M_B	4.8	6.4	6.4	8.0	25.6
TOTAL	12.0	12.8	13.6	20.8	59.2

Between Height of seedling (H) and Mechanisms (M)

	H_1	H_2	H_3	Total
M_A	11.2	8.8	13.6	33.6
M_B	8.0	9.6	8.0	25.6
Total	19.2	18.4	21.6	59.2

Appendix-H

COMPARISON OF TREATMENT MEANS

1. Comparison of treatment means for average number of seedlings/hill

Standard error difference due to Rate of Picking,

$$S.E\ (d) = \sqrt{\frac{2 \times 0.0107}{3 \times 3 \times 2}} = 0.0345$$

Critifical difference = $t_{46,0.05}$ x S.E(d) = 2.014 x 0.0345

= 0.0695

Treatment mean difference between rates of picking of,

60 and 90 hills/min = 0.1424*; 60 and 120 hills/min = 0.1563*

60 and 150 hills/min = 0.2590*; 90 and 120 hills/min = 0.0139

90 and 150 hills/min = 0.1166*; 120 and 150 hills/min = 0.1027*

Standard error of difference due to seedling height,

$$S.E(d) = \sqrt{\frac{2 \times 0.0107}{3 \times 4 \times 2}} = 0.0299$$

Critical difference = 2.014 x 0.0299 = 0.06014

Treatment mean difference at 60 hills/min beween the seedling height of

30 and 25 cm = 0.198*; 30 and 20 cm = 0.180*

25 and 20 cm = 0.378*

At 90 hills/min, between seedling heights of 30 and 25 cm

= 0.042;

30 and 20 cm = 0.28*; 25 and 20 cm = 0.238*

At 120 hills/min, between seedling heights of,

30 and 25 cm = 0.090*; 30 and 20 cm = 0.320*;

25 and 20 cm = 0.230*

At 150 hills/min, 30 and 25 cm = 0.040; 30 and 20 cm=0.100*

25 and 20 cm = 0.140*

2. Comparison of treatment means for plant hill missing

Standard error of difference due to Rate of Picking,

$$S.E(d) = \sqrt{\frac{2 \times 0.3334}{3 \times 3 \times 2}} = 0.1925$$

Critical difference = $t_{46,0.05}$ x S.E(d) = 2.014 x 0.1925

= 0.3877

Treatment mean difference between rates of picking of,

60 and 90 hills/min = 1.19* ; 60 and 120 hills/min= 3.20*

60 and 150 hills/min= 11.59*; 90 and 120 hills/min= 2.01*

90 and 150 hills/min = 10.40*; 120 and 150 hills/min = 8.39*

Standard error difference due to Mechanism,

$$S.E(d) = \sqrt{\frac{2 \times 0.3334}{3 \times 4 \times 3}}$$

$$= 0.1361$$

Critical difference = 2.014 x 0.1361 = 0.2741

Treatment mean difference between the mechanism at rate of picking of

60 hills/min = 1.87*; 90 hills/min = 3.20*

120 hills/min = 5.07*; 150 hills/min = 0.36*

3. Comparison of treatment means for seedling damage

Standard error of difference for Rate of Picking,

$$S.E(d) = \sqrt{\frac{2 \times 0.1805}{3 \times 3 \times 2}} = 0.1416$$

Critical difference = $t_{46,0.05}$ x S.E(d) = 2.014 x 0.1416

= 0.2852

Treatment mean difference between rates of picking of,

60 and 90 hills/min = 0.04451; 60 and 120 hills/min = 0.0889

60 and 150 hills/min= 0.4890*; 90 and 120 hills/min= 0.0444

90 and 150 hills/min = 0.4444; 120 and 150 hills/min= 0.4000*

Standard error of difference for mechanisms, $S.E(d) = \sqrt{\frac{2 \times 0.1805}{3x4x3}}$

= 0.1001

Critical difference = 2.014 x 0.1001 = 0.2017

Treatment mean differences between mechanisms at rate of picking of 60 hills/min = 0.27*; 90 hills/min = 0

120 hills/min = 0.0890; 150 hills/min = 0.533*

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Appendix-I

Table I.1 Means and standard deviations of various performance indices

		Rates of picking (hills/min)			
		60	90	120	150
		1	2	3	4
Av. no. of seedlings/hill at various seedling heights (cm)					
30	Mean	2.36	2.11	2.07	1.99
	S.D.	1.09	1.22	1.24	1.33
25	Mean	2.17	2.15	2.16	1.95
	S.D.	1.24	1.13	1.25	1.39
20	Mean	2.55	2.39	2.39	2.09
	S.D.	1.20	1.25	1.32	1.48
Percentage of plant hill missing for Mechanism A and B					
M_A	Mean	4.09	5.16	5.69	16.80
	S.D.	0.59	0.40	0.59	0.65
M_{BZ}	Mean	5.96	7.82	10.76	16.44
	S.D.	0.67	0.63	0.67	0.40
Percentage of seedling damage for Mechanism A and B					
M_A	Mean	0.80	0.71	0.80	1.42
	S.D.	0.38	0.45	0.38	0.50
M_B	Mean	0.53	0.71	0.71	0.89
	S.D.	0.38	0.25	0.45	0.45

Appendix-J

Table J.1 Power consumption of the mechanism at various tests

			Time for one revolution of the energy meter disc(sec) With mechanism in operation	Without mechanism in operation	Power consumed (watts)
			1	2	3
M_A	P_1	H_1	95.0	93.0	13.58
		H_2	95.0	93.0	13.58
		H_3	95.0	93.0	13.58
	P_2	H_1	96.0	92.5	20.16
		H_2	96.0	92.5	20.16
		H_3	96.0	92.5	20.16
	P_3	H_1	96.5	92.5	26.89
		H_2	96.5	92.5	26.89
		H_3	96.5	92.5	26.89
	P_4	H_1	97.0	92.0	33.62
		H_2	97.0	92.0	33.62
		H_3	97.0	92.0	33.62
M_B	P_1	H_1	95.0	92.5	17.07
		H_2	95.0	92.5	17.07
		H_3	95.0	92.5	17.07
	P_2	H_1	98.5	94.5	25.78
		H_2	98.5	94.5	25.78
		H_3	98.5	94.5	25.78

Table J.1 contd...

1		1	2	3
P_3	H_1	97.0	92.0	33.62
	H_2	97.0	92.0	33.62
	H_3	97.0	92.0	33.62
P_4	H_1	95.5	89.5	42.12
	H_2	95.5	89.5	42.12
	H_3	95.5	89.5	42.12