International specialized medium for agricultural mechanization in developing countries

ISSN 0084-5841

AMA

AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

VOL.54, NO.2, SPRING 2023

FARM MACHINERY INDUSTRIAL RESEARCH CORP.

WARNING! - Beware of Fraud

Be sure 3 points below:

★ AMA shall never charge you
★ Who is your Co-editor?
★ Wait 2 or 3 years for publishing

AMA Fake site: https://www.shin-norinco.com/
AMA True site: https://www.agriculturalmechanization.com/
E-mail address of AMA: ama@shin-norin.co.jp-

FARM MACHINERY INDUSTRIAL RESEACH CORP.

International specialized medium for agricultural mechanization in developing countries

ISSN 0084-5841

AMA

AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

VOL.54, No.2, SPRING 2023

Edited by

YOSHISUKE KISHIDA

Published quarterly by

Farm Machinery Industrial Research Corp.

in cooperation with

The Shin-Norinsha Co., Ltd.

and

The International Farm Mechanization Research Service

TOKYO

Editorial, Advertising and Circulation Headquarters
1-2-5, Kanda Jimbo-cho, Chiyoda-ku, Tokyo 101-0051, Japan
URL: https://www.agriculturalmechanization.com/
E-Mail: ama@shin-norin.co.jp

This is the 196th issue since its maiden issue in the Spring of 1971

EDITORIAL

SDGs is being called for all over the world today. This means that as the number of people increases, people and nature on this earth must live together in harmony. Development must also be sustainable. Many people around the world are thinking about how to achieve sustainable development. It is a difficult question, and there are many things that we really don't know whether the symbiosis between man and the earth can be sustained or not.

There are many scientists who say that it is not possible. Agriculture is an essential part of man's symbiosis with the natural environment of the earth. In other words, agriculture is the process by which people work in harmony with the living systems of the earth, and good agriculture is what makes sustainable harmony possible. Of course, forestry is also a part of this.

Japan is blessed with many mountains and forests, and we must all work together to create an environment in which agriculture can take place on these forests and farmlands. The necessary work must be done promptly when it is needed. Mechanization of agriculture and forestry is essential.

On the other hand, the war between Russia and Ukraine has made it difficult to export grain, especially to the African region, and the number of starving people is increasing drastically. New agriculture and agricultural mechanization in such regions are essential. All those involved in agricultural machinery must help Africa.

When considering the future of agricultural mechanization, there is one new technology that is different from the past. This is the robotization and unmanned use of agricultural machinery. The development of computers has dramatically increased the ability of machines to process information. Computers that can react like humans, such as generative AI, are also emerging. Artificial intelligence will be able to go into agricultural machinery and manipulate it to work like a human, or better than a human. In thinking about agricultural mechanization in developing countries, farmers have all been thinking about structures that are easy to use, simple to operate, and easy to repair when broken. From now on, however, as small agricultural robots are developed, they will do all the work, and what farmers should do is turn the machine on and, when it is done, carry it to the next place it needs to go. When these new farm robots can be mass-produced and become cheaper, farmers in developing countries will be more likely to use them. A new world of agricultural machinery is sure to open up. I believe that research and development of agricultural robots is the most important factor in the mechanization of food production and agriculture in the future. Let us all work together in the research and development of agricultural robots!

Yoshisuke Kishida
Chief Editor
September, 2023

CONTENTS

AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

Vol.54, No.2, Spring 2023

Effect of Cutting Blade Parameters on Harvesting of Sorghum Stalks

by

Mrudulata Deshmukh
Assistant Professor
Department of Farm Power & Machinery
Dr. Panjabrao Deshmukh Krishi Vidyapeeth,
Akola. (MS) INDIA
mrudulatad@rediffmail.com

S. K. Thakare
Associate Professor
Department of Farm Power & Machinery
Dr. Panjabrao Deshmukh Krishi Vidyapeeth,
Akola. (MS) INDIA
skthakare@gmail.com

R. B. Ghorade
Senior Research Scientist
Sorghum Research Unit
Dr. Panjabrao Deshmukh Krishi Vidyapeeth,
Akola.(MS) INDIA
akola@millets.res.in

Abstract

The laboratory setup of rotary cutting mechanism having different component such as rotary disc, blade, torque sensor variable frequency drive, belt and pulley, plant holder was developed to study effect of blade angle on force requirement to cut the sorghum stalk. Straight plane blade was used during study. The combination of blade bevel angle 250 and blade shear angle 250 recorded minimum force for cutting stalks of three selected varieties. The minimum force was observed at the combination of blade rake angle 200 and blade shear angle 350 for variety CSV-20. The minimum force was observed at the combination of blade shear angle 350 and velocity 350 rpm for variety CSV-23 and CSH-9 respectively. The variety CSH-9 required minimum force for all combination of blade parameter.

Keywords: rotary, variable frequency drive, shear, rake angle

Introduction

India covers 34 percent of total sorghum grain per annum. It is being cultivated in Maharashtra both for grain and fodder during kharif (area 13.84 lakh ha) and rabi (area 30.17 lakh ha) The percentage area under rabi sorghum (64 percent) is more than kharif sorghum (36 percent) area. Contrary to this, production and average yields of kharif sorghum are higher (more than 1 tonnes/ha) than the average yield in rabi (0.6 tonne/ha) (http://vistar.nic.in/document/chapter/79.htm). The present practice of harvesting in India is carried out using manually operated sickle. The total harvesting of sorghum requires two stages cutting of plant, one at the top for separating cobs and the other at the bottom for fodder. Hence, double labor is required for harvesting sorghum crop. About 25 percent of the total labour for grain production is required for harvesting operation alone. The urbanization, resulting in shortage of labor during the peak harvesting season. This condition restrains the farmer to maximize the productivity of his land and at the same time subjects his crops to losses due to untimely harvesting. This situation necessitates the introduction of a system operation that will require minimal turn-around time in crop production in order to catch up with the next planting season and will improve the harvesting operation. Considering all the above points, it was felt to tackle the problem of harvesting sorghum crop by proposing the harvesting mechanism. The stalk cutting machines are either reciprocating type or rotary type. The latter is being increasingly used in these operations due to its simplicity in construction, low maintenance cost and ability to cut both small and large diameter stalks (McRandal and McNulty, 1978)

Materials and Methods

The first stage of the study was to design a special cutting system for sorghum plant with due attention to physical properties of sorghum stalk. With due attention to specification of systems and physical properties of sorghum stalk rotary cutting systems was selected.

Development of Laboratory Set Up

The fabrication of the set up was carried out in the workshop of department of Farm Power and Machinery, Dr. Panjabrao Deshmukh Krishi Vidyapeeth. Akola (MS)

i) Frame

The main frame made of MS angles having dimensions 1000 × 600 mm was fabricated to mount all the components of the cutting mechanism. One secondary frame is mounted on the main frame having dimensions 400 × 600 × 400 mm. An electric motor is mounted on the secondary frame.

ii) Main Shaft

The main shaft made of EN-19 material and size ϕ55 × 458 mm length was centrally mounted on the frame passing through the secondary frame. The main shaft of the mechanism carries two rotating discs, one at the top for cutting cob peduncles and another at the bottom for cutting stalks.

iii) Rotary Disc

The disc made of mild steel having specifications ϕ500 × 10 mm thick was mounted at bottom (for cutting stalks) and at top end (for cutting cob peduncles) of the main shaft.

iv) Cutting Blades

Straight plain blade made up of EN-19 material was selected for the study. The dimensions of straight plain blade were 230 × 60 × 10 mm.

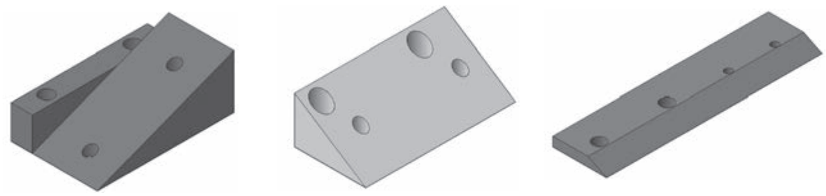
v) Angle sim

The angle sims made of mild steel were fabricated for facilitating the angles of the blade (**Fig. 1**).

vi) Torque Sensor

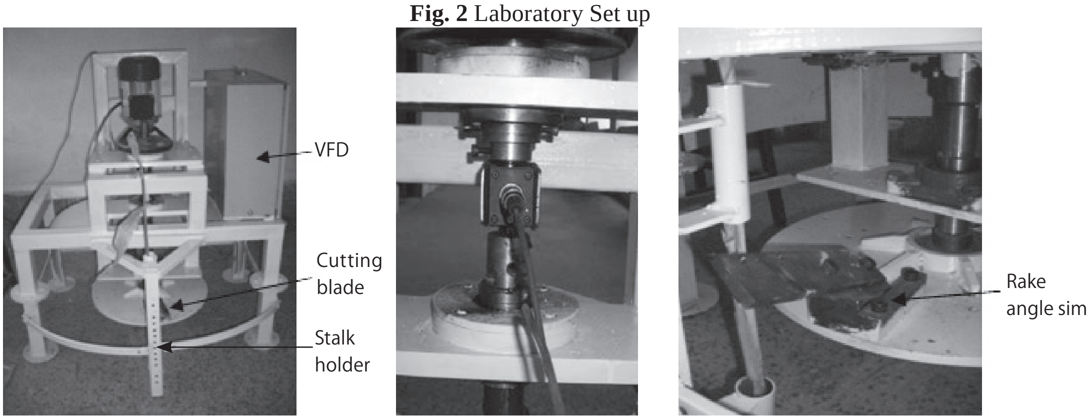
Futek Sensit Torque sensor (Model - TRS - 300) was aligned on the main shaft between the two bearings. The torque sensor was used for measuring the cutting torque at various combinations of blade angle and speed of disc. The torque sensor has software in which observations of the cutting torque were available

Fig. 1 Blade type and angle sims



Straight plain blade | Shear angle sim | Rake angle sim

Fig. 2 Laboratory Set up



Rotary cutting mechanism | Torque sensor | Rake angle arrangement

Table 1 Effect of blade bevel angle and blade shear angle on force for cutting sorghum stalks

Sr. No.	Blade bevel angle, degree	Force, N											
		Variety											
		CSV-20				CSV-23				CSH-9			
		Blade shear angle, degree											
		25	30	35	Mean	25	30	35	Mean	25	30	35	Mean
1	25	1.40	8.00	2.43	3.94	1.83	5.31	2.67	3.27	1.11	2.74	1.67	1.84
2	35	16.96	3.26	2.85	7.69	8.14	2.59	2.98	4.57	5.89	1.70	1.76	3.11
3	45	3.80	3.11	2.50	3.14	2.88	2.95	2.83	2.89	1.78	1.54	1.95	1.75
	Mean	7.39	4.79	2.60		4.28	3.62	2.83		2.93	1.99	1.79	
	F - test		S				S				S		
	SE(m)±		0.959				0.187				0.073		
	CD(5%)		2.662				0.519				0.203		

S - Significant

in data logging as well as in the form of live graph during the trials.

vii) Electric Motor

MGM Varvel 1.5 kW, 1440 rpm electric motor with ϕ100 was used for power transmission.

viii) Variable Frequency Drive

Delta make, AC drive (Model VED 015M21A) was used for speed variation.

Evaluation of Rotary Cutting Mechanism

Independent Variables:

I) Varieties - 3 (CSV-20, CSV-23 & CSI-9)

II) Blade bevel angles - 3 levels (25°, 35°, 45°)

III) Blade shear angles - 3 levels (25°, 30°, 35°)

IV) Blade rake angles - 3 levels (20°, 0°, -20°)

V) Blade velocity - 3 levels (350, 500, 650 rpm)

Dependent Variable: Peak force

Replications: 3

Design : CRD

As per the experimental design, the samples of three varieties of the sorghum stalks were hold in the stalk holder and the disc was rotated at three speeds. The trials were repeated thrice.

Results and Discussion

The effect of combination of blade parameters on force on cutting sorghum talks of three selected varieties are presented herewith.

Effect of Blade Bevel Angle and Blade Shear Angle

The minimum value of force required for cutting sorghum stalk was obtained at combination of blade bevel angle 25° and blade shear angle 25° where as the maximum force was observed at the combination of blade bevel angle 35° and blade shear angle 25° for all three selected variety. It was also observed that the force was minimum for variety CSH-9 and maximum for variety CSV-20 for selected all three bevel angles of blade. The statistical analysis of the data as a combine effect of blade bevel angles and blade shear angles shows significant difference at 5% level of significance in the mean values of forces for the cutting stalk of selected all three sorghum varieties.

Effect of Blade Rake Angle and Blade Shear Angle

For the variety CSV-20, the minimum value of force (1.61 N) required for cutting sorghum stalk was observed at the combination of blade rake angle 20° and blade

Table 2 Effect of blade rake angle and blade shear angle on force for cutting sorghum stalks

Sr. No.	Blade rake angle, degree	Force, N											
		Variety											
		CSV-20				CSV-23				CSH-9			
		Blade shear angle, degree											
		25	30	35	Mean	25	30	35	Mean	25	30	35	Mean
1	20	18.20	6.66	1.61	8.82	8.12	4.49	2.45	5.02	6.12	2.91	1.28	3.44
2	0	2.33	2.47	2.54	2.45	1.88	2.90	2.24	2.34	1.45	1.31	1.71	1.49
3	-20	1.62	5.25	3.63	3.50	2.84	3.47	3.81	3.37	1.20	1.75	2.38	1.78
	Mean	7.39	4.79	2.60		4.28	3.62	2.83		2.93	1.99	1.79	
	F - test		S				S				S		
	SE(m)±		0.959				0.187				0.073		
	CD(5%)		2.662				0.519				0.203		

S - Significant

Table 3 Effect of blade shear angle and blade velocity on force for cutting sorghum stalks

Sr. No.	Shear angle (degree)	Force, N											
		Variety											
		CSV-20				CSV-23				CSH-9			
		Velocity, rpm											
		350	500	650	Mean	350	500	650	Mean	350	500	650	Mean
1	20	8.92	8.68	4.56	7.39	4.11	4.98	3.75	4.28	3.29	3.28	2.20	2.93
2	0	4.86	4.33	5.19	4.79	3.15	4.20	3.50	3.62	2.16	1.95	1.87	1.99
3	-20	1.67	2.04	4.07	2.60	1.57	2.88	4.04	2.83	1.14	1.74	2.49	1.79
	Mean	5.15	5.01	4.61		2.94	4.02	3.76		2.20	2.33	2.19	
	F - test		S				S				S		
	SE(m)±		0.959				0.187				0.073		
	CD(5%)		2.662				0.519				0.203		

S - Significant

shear angle 35°. When the variety CSV-23 was used for the experimentation, significant difference was observed in the mean values of force as a combine effect of blade rake angles and blade shear angles. The minimum value of force (1.88 N) required for the cutting sorghum stalk of variety CSV-23 was observed at the combination of blade rake angle or blade shear angle 0° and blade shear angle 25°. For CSH-9 the minimum value of force (1.20 N) required for cutting sorghum stalk was observed at the combination of blade rake angle -20° and blade shear angle 25°.

Effect of Blade Shear Angle and Blade Velocity

Table 3 represents the effect of blade shear angle and blade velocity on the force for cutting sorghum stalk of selected varieties. The data from the table revealed that significant difference observed in mean values of force as combine effect of shear angle and blade velocity. The minimum value of force 1.67, 1.57 and 1.14 N for cutting sorghum stalk was observed at the combination of blade shear angles 35° and blade velocity 350 rpm for the verities CSV-20 CSV-23 and CSH-9 respectively. The maximum value of force was recorded for cutting Sorghum stalk at combination of blade shear angle 25° and blade velocity 350 rpm for the varieties CSV-20 and CSH-9 whereas for the variety CSV-23 it was observed at the combination of blade shear angle 25° and blade velocity 500 rpm.

Conclusions

1. The combination of blade bevel angle 25° and blade shear angle 25° recorded minimum force for cutting stalks of three selected varieties.
2. The minimum force was observed at the combination of blade rake angle 20° and blade shear angle 35° for the variety CSV-20
3. The minimum force was observed at the combination of blade rake angle 0° and -20 with blade shear angle 25° for the varieties CSV-23 and CSH-9 respectively.
4. The variety CSH-9 required minimum force for all combinations of blade parameters.

REFERENCES

Ghahraei, O. D., A. Ahmad, H. S. Khalina and J. Othman. 2011. Cutting test of knefe stems. Transition of ASAE Vol. 54(1): 51-56.

McRandal, D. M. and P. B. McNulty. 1978. Impact cutting behaviour of forage Crops I. Mathematical models and laboratory tests. J. Agril. Engg. Res. Vol.23 (3): 313-328.

Perssons, S. 1987. Medianics of cutting plant Material. ASAE publications, Michigan, USA.

Prasad, J. and C. P. Gupta. 1975. Mechanical properties of Maize stalk as related to harvesting. J. Agril.Engg - Res. Vol. 20(1): 73-87.

(http://vistar.nic.in/document/chapter/79.htm

■■

Fig. 3 Effect of blade bevel angle and blade shear angle on force for cutting sorghum stalks

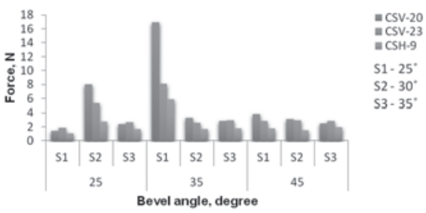


Fig. 4 Effect of blade rake angle and blade shear angle on force for cutting sorghum stalks

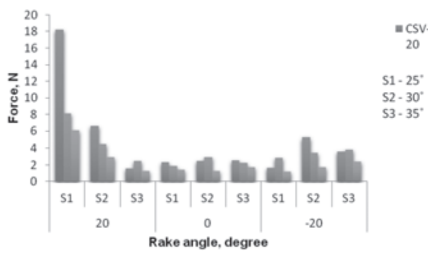
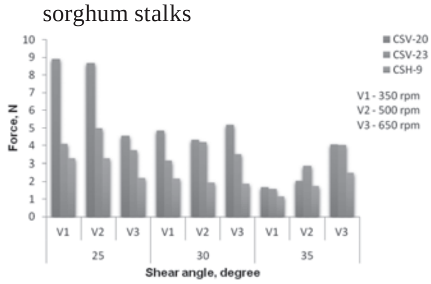


Fig. 5 Effect of blade shear angle and blade velocity on force for cutting sorghum stalks



Dynamics of Farm Power Availability in Eastern Region of India

by
Prem K. Sundaram
Division of Land & Water Management,
ICAR - Research Complex for Eastern Region,
Patna, Bihar, INDIA

Bikash Sarkar
Division of Land & Water Management,
ICAR - Research Complex for Eastern Region,
Patna, Bihar, INDIA

Roaf A. Parray*
Division of Agricultural Engineering,
Indian Agricultural Research Institute,
Pusa, New Delhi, INDIA
*Corresponding author:
rouf.engg@gmail.com

Indra Mani
Vice Chancellor, Vasantrao Naik
Marathwada Krishi. Vidyapeeth,
Parbhani, Maharashtra, INDIA

Pawan Jeet
Division of Land & Water Management,
ICAR-Research Complex for Eastern
Region, Patna, Bihar, INDIA

Sanjay Patel
College of Agricultural Engineering,
Dr. RP Central Agriculture University,
Pusa, Samastipur, Bihar, INDIA

A. Upadhyaya
Division of Land & Water Management,
ICAR - Research Complex for Eastern
Region, Patna, Bihar, INDIA

Abstract

The agriculture sector in India has witnessed a considerable decline in the use of animal and human power in agriculture related activities. The trend has paved a way for a range of agricultural tools and increased the level of mechanization on Indian farms. However, this increase in mechanization has been skewed towards some states and regions of the country. The eastern region of the country comprising Assam, Bihar, Chhattisgarh, Eastern Uttar Pradesh (UP), Jharkhand, Odisha and West Bengal states, holds promise for a Second Green Revolution in the country. However, the production levels of agriculture have remained low in this region mainly due to lack of location-specific production technologies, natural calamities like floods, waterlogging, drought, inadequate timely supply of critical inputs and social constraints. To improve the productivity in this region, mechanization of farms is of critical importance. The farm power availability in this region has increased from 1.66 to 1.94 kW/ha during 2014-17. The present study tries to understand the dynamics of farm power availability in eastern region of India, so as to take remedial measures for improved mechanization and in turn crop productivity in the region.

Keywords: farm power, mechanization, eastern region of India, mechanical power

Introduction

The eastern region of India, comprises Assam plains, Bihar, Chhattisgarh, Eastern Uttar Pradesh (UP), Jharkhand, Odisha and West Bengal states. It occupies about 21.85% of the total geographical area of the country (**Fig. 1**). Eastern Uttar Pradesh is not a state, but spans over 28 districts in eastern part of Uttar Pradesh state. The Eastern region of India is endowed with rich natural resources, with abundant water and fertile land resources, yet the production and productivity are low. The small and scattered land holdings, poor groundwater utilization and lack of infrastructure are some of the major constraints preventing

Fig. 1 States in Eastern Region of India

enhanced crop production in these states (Bhatt et al., 2012).

Agricultural productivity is greatly influenced by power availability and its optimum use on the farms. The farm power availability is an indicator of the health of the agrarian situation in a state. Over the last few years, there has been considerable progress in agricultural mechanization in India. During last 5 decades, farm power availability in India has increased considerably from 0.25 kW/ha in 1951 to 2.24 kW/ha in 2017 (Mehta et al., 2019). Mechanization in agriculture progressed faster in Northern region compared with Eastern region of India. Empirical evidence confirms that there is a strong correlation between farm mechanization and agricultural productivity. States with a greater availability of farm power show higher productivity as compared to others (Singh et al., 2011).

The first Green Revolution in India ensured food security. The second Green Revolution aimed at creating sustainable agriculture by leveraging advancements in technology has to come from Eastern region of India as its potential is yet to be fully exploited. The majority of farming families in this region are at the bottom of the pyramid. Increasing their net returns from agriculture is the only solution for alleviating their poverty. However, the returns from agriculture are significantly lesser in eastern India compared to the north-western states. The crop yields are low and almost stagnating in eastern India compared to the north-western and other parts of the country. For example, average yield of rice is around 2.0-2.5 tons/ha in Bihar compared to 5.0 tons/ha in Haryana and 6.0 tons/ha in Punjab. In the case of wheat, the yield is around 2.5 tons/ha in Bihar, much below the yield levels in Punjab and Haryana (4.5-5.0 tons/ha) (Joshi and Khan, 2017).

The purpose of this study was to comprehend about the changes in farm power sources and farm power availability over the years in Eastern India. The study has been carried out by collecting information from different government data banks and analyzing mission documents like Sub-Mission on Agricultural Mechanization (SMAM) (Anonymous, 2018).

Importance of the Study

Farm mechanization plays a positive role in increasing crop productivity, reducing drudgery and also providing employment in rural areas through generation of opportunities for operators, mechanics, salesmen etc. The purpose of this study was to comprehend about the changes in farm power sources and farm power availability over the years in Eastern India. The study has been carried out by collecting information from different government data banks and inferences were drawn about change in pattern of different farm power sources like number of agriculture workers, draught animal population, number of tractors and power tillers, number of electric motors and diesel engines. Farm power sources and their availability in different districts of eastern region of India has been spatially and temporally compared. Inferences drawn from the study may help and guide the State Governments/researchers/students about the current status of farm power in the eastern region of India and also to develop strategies for promoting farm mechanization.

Dynamics of Land-owning Pattern in Eastern Region of India

Land holding pattern is crucial factor in deciding use of farm power and machines. Costly machines become uneconomical for small sized farms. In India, on the basis of area of land holding, farmers are divided into five major size groups (**Table 1**). During 2001-2016, there has been consistent increase in number of land holdings in marginal farmer's category (< 1.0 ha), both in eastern region as well as in India. However, in Eastern region the increase has been significantly higher (14.42%) compared to national average of 5.57%. This is indicative of the fact that fragmentation of land in Eastern region is more accelerated as compared to India. Fragmentation of small farmers' land (1.0-2.0 ha) is the major contributor in increasing the percentage of land holding of marginal farmers (**Table 1**). However, as far as whole country is concerned, Semi-medium farmers (2.0-4.0 ha) are the major contributor.

In eastern region of India, Bihar leads in percentage of marginal farmer (91.2%) among all the seven states. It is followed by Eastern Uttar Pradesh (85%), West Bengal (82.8%), Odisha (74.7%), Jharkhand (70%), Assam (68.2%) and Chhattisgarh (60.7%). Odisha saw the maximum increase in percentage of number of marginal farmers from 56.4% to 74.7% during 2001-2016 followed by Eastern UP (69 to 85%) during the same period (**Fig. 2**). The major contributors in increasing the percentage in marginal farmers in both the states were division of land of small farmers (1.0-2.0 ha). This is a major concern as small farms (1.0-2.0 ha) are getting divided more and more. Rest of the states also follow similar pattern except Chhattisgarh. In Chhattisgarh, the division of land

Table 1 Changes in pattern of number of operational holding (%) by major size groups in Eastern region and India

Major Size group	Eastern Region			India		
	2001	2016	Change	2001	2016	Change
Marginal farmers (<1 ha)	67.73	82.15	14.42	62.88	68.45	5.57
Small farmers (1-2 ha)	18.71	11.56	(-)7.15	18.92	17.62	(-)1.3
Semi-Medium farmers (2-4 ha)	9.94	4.99	(-)4.95	11.69	9.55	(-)2.14
Medium farmers (4-10 ha)	3.28	1.18	(-)2.1	5.48	3.8	(-)1.68
Large farmers (>10 ha)	0.35	0.12	(-)0.23	1.02	0.57	(-)0.45

of semi-medium farmers (2.0-4.0 ha) and medium farmers (4.0-10.0 ha) are the major contributor in increasing the percentage of marginal farmers. Fragmentation of land had led to challenges in economies of scale of farm machinery. This acts as a deterrent in augmentation of farm mechanization.

Farm Power Sources and Its Availability in Eastern Region of India

Agricultural workers, draught animals, tractors, power tillers, diesel engines and electric motors are major sources of farm power in Indian agriculture. The pace of mechanization in Eastern region of India is slow due to constraints like fragmented lands, hilly topography, socio-economic conditions, high cost of transport, lack of institutional financing and lack of farm machinery manufacturing industries (Mehta et al., 2014). To compare it across states the numbers of farm power sources were divided by the respective net sown area (NSA) of the states. The net sown area of Assam, Bihar, Chhattisgarh, Eastern UP, Jharkhand, Odisha and West Bengal were 2.75, 5.67, 4.73, 5.49, 1.54, 5.62, and 5.30 million ha, respectively.

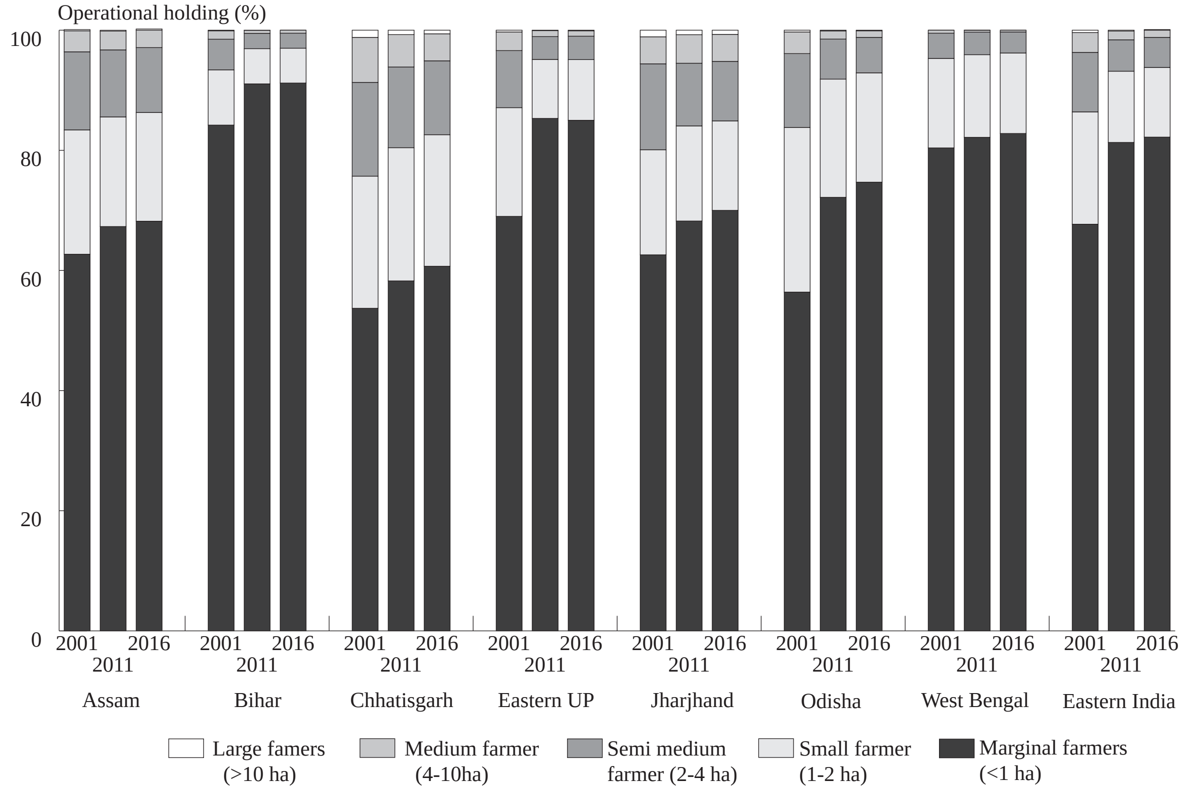
Dynamics of Agricultural Workers in Eastern Region of India

A person who works on another person's land for wages in money or share is regarded as an agricultural worker/labourer. The availability of workers in agriculture is crucial for sustaining agricultural production system. All over India, the agricultural workers have grown consistently since 1951 (Gupta, 2016). There has been consistent increase in number of agricultural workers across all the seven states during 2001-17. The overall increase in agricultural workers in eastern Region was about 11% during 2001-2017. The agricultural workers in the states of Assam, Bihar, Chhattisgarh, Eastern UP and West Bengal increased at almost same rate of 4.0%. Similarly, for Jharkhand it was 8.0 percent. However, there was tremendous increase (43%) in case of Odisha. This may be due to increased number of marginal and small farmers along with number of land holding as stated earlier. The average land holding size in 2016 in Odisha was 0.95 ha (Anonymous, 2020). Among states, Bihar and Odisha have maximum number of agricultural workers per 1000 ha of net sown area (**Fig. 3**). Chhattisgarh has the least number of agricultural workers (600 per 1000 ha of NSA).

Draught Animal Dynamics

Animals assist in crop production (ploughing, planting, and weeding), reducing drudgery and creation of wealth. Animal traction greatly helps in maintaining food security in smallholder farming systems. Food production, distribution and rural trade are also assisted through animal-powered transport. Animals save household time and effort by carrying water and fuel wood. Ani-

Fig. 2 Changes in pattern of number of operational holding (%) by major size groups in states of eastern region (2001-2016)



mal power is also used for water-lifting, milling and transporting crop. Many different types of draught animal are employed, particularly cattle (oxen, bulls and cows), buffaloes, horses, mules, donkeys and camels in Indian farms. However, with the introduction of mechanical farm power, their population is slowly decreasing. Also, availability of fodder round the year is a major bottleneck for their adoption.

Jharkhand state had the maximum draught density followed by Assam and Odisha during 2014-17. There was general trend of decrease in draught animal density among all the states. This indicates the increased preference of adoption of mechanized power. The maximum decrease in draught power density was in Eastern UP followed by West Bengal and Odisha (**Table 2**).

Table 2 Draught animal dynamics in eastern region of India (2014-17)

States	Draught animal density (No. of draught animals per 1000 ha NSA area)		Difference in draught animal density during the period
	2014	2017	
Assam	883.5	848.8	-3.7
Bihar	94.0	90.3	-5.5
Chhattisgarh	651.6	626.0	-17.9
Eastern UP	140.6	135.0	-78.8
Jharkhand	1329.8	1251.0	-25.7
Odisha	672.8	646.3	-26.5
West Bengal	455.2	437.3	-34.8
Eastern Region	484.3	464.0	-20.4

Table 3 Tractor dynamics in eastern region of India (2014-17)

States	Tractor density (No. of tractors per 1000 ha NSA area)		Percentage increase in number of tractors
	2014	2017	
Assam	12 (4.95)	17 (5.34)	37.9
Bihar	28 (23.33)	38 (24.39)	33.8
Chhattisgarh	15 (10.38)	23 (12.28)	51.3
Eastern UP	33 (26.62)	42 (26.49)	27.3
Jharkhand	9 (2.05)	17 (2.96)	84.6
Odisha	23 (18.98)	26 (16.37)	10.4
West Bengal	18 (13.69)	25 (15.24)	42.4
Eastern Region	22 (100)	29 (100)	31.9

(Data in parenthesis show the share of individual state in Eastern India)

Dynamics of Tractors in Eastern Region of India

Tractor is the major mechanical power source used on Indian farms. India has one of the largest tractor manufacturing industries in the world. The Indian tractor industry is witnessing a double-digit growth. The sale of tractors in India was 217,456 in 2002, 661,431 in 2013 and 8,78,476 units in 2019 (Mehta et al., 2014; Mishra, 2019). The average tractor use in India is still lower by the world standard, and a huge disparity exists on its uses across states (regions) in the country.

To compare tractor population among the seven states, tractor density was calculated. Tractor density was calculated by dividing the number of tractors by respective net sown area of the states. In eastern region of India, Eastern UP has the maximum tractor density of 42 tractors per 1000 ha net sown area in 2017 followed by Bihar (38), Odisha (26), West Bengal (25), Chhattisgarh (23), Jharkhand (17) and Assam (17). The average tractor density of eastern region increased from 22 to 29 tractors per 1000 NSA during the period 2014-2017 (**Table 3**). The average tractor density of eastern region was 29 in 2017, which is below the national average of 33 (Mehta et. al., 2019). The maximum percentage growth in number of tractors was in Jharkhand state (84.65%) during 2014-17, but its overall share in 2017 was very low (2.96%). Sundaram et al. (2019) also reported increasing trends of tractor adoption in Jharkhand. Chhattisgarh and West Bengal also witnessed a growth of 51.3 and 42.4%, respectively. The changing pattern in number of tractors per 1000 ha NSA during 2014-17 in eastern region was

Fig. 3 Dynamics of Agricultural Workers in Eastern Region of India (2014-17)

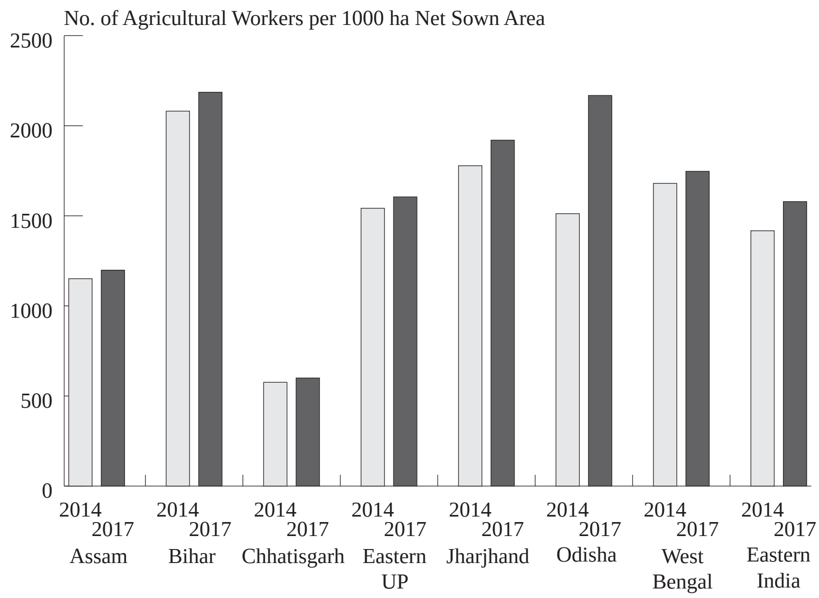


Table 4 Power tiller ownership pattern in eastern region (2014-17)

States	No. of power tillers per 1000 ha net sown area		Percentage increase in number of Power tillers
	2014	2017	
Assam	25.62 (27.8)	27.51 (23.8)	7.4
Bihar	8.95 (20.0)	9.25 (16.5)	3.4
Chhattisgarh	1.13 (2.1)	1.76 (2.6)	56.7
Eastern UP	0.78 (1.7)	0.97 (1.7)	24.4
Jharkhand	1.94 (1.2)	2.86 (1.4)	47.4
Odisha	12.91 (28.6)	21.08 (37.2)	63.2
West Bengal	8.91 (18.6)	10.09 (16.8)	13.2
Eastern Region	8.16 (100)	10.23 (100)	25.4

(Data in parenthesis show the share of individual state in Eastern India)

well described by spatial distribution (**Fig. 4**).

Dynamics of Power Tillers in Eastern Region of India

The market for power tillers in India was estimated at 49,000 numbers during 2016-17 (Anonymous, 2017). The market for power tillers in India is mainly concentrated in the eastern and southern parts of the country owing to the higher percentage of marginal and small farmers and paddy-based farming in these regions. The maximum share of power tiller in Eastern region was with Odisha (37.2%) in 2017 followed by Assam, West, Bengal, Bihar, Chhattisgarh, Eastern UP and Jharkhand. Assam recorded maximum number of power tiller per 1000 ha NSA, but had only 23.8% share in Eastern region in 2017 (**Table 4**). During 2014-17, Odisha recorded maximum percentage increase in number of power tillers (63.2%) followed by Chhattisgarh, Jharkhand, Eastern UP, West Bengal, Assam and Bihar. Overall, there was 25.4% increase in number of power tillers in eastern region of India during 2014-17.

Dynamics of Electric Motors in eastern Region of India

During 2014-17, the maximum growth in number of electric motors was observed in Odisha state (23.07). It grew from 66 to 81 electric motors per 1000 ha NSA. Odisha was followed by Chhattisgarh (79), Eastern UP (51), West Bengal (51), and Bihar (48) in 2017 (Table 5). Odisha also had the maximum share in 2014 as well as in 2017. Assam and Jharkhand have very a smaller number of electric motors per 1000 NSA. The reason may be the hilly and plateau terrain causing difficulty in installing electricity grid. In Assam, the installed electricity capacity was also very less.

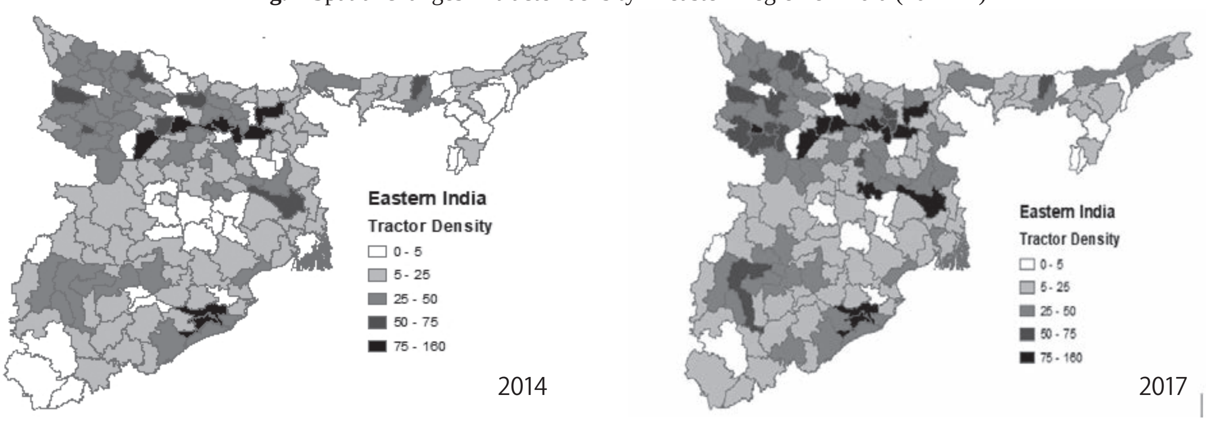
Dynamics of Diesel Engines in Eastern region of India

Eastern UP, Bihar and West Bengal lead in number of diesel engines in eastern region. Their share in eastern region was about 93% in 2017 (**Table 6**). Remaining 7% was shared by other four states collectively. Assam had the lowest number (less than 1) of diesel engine per 1000 ha NSA. However, during the period 2014-17, it recorded maximum percent increase (70%) in number of diesel engines in eastern region followed by Jharkhand (15%) and Eastern UP (13%). From **Tables 5** & **6** and **Fig. 5**, it can be inferred that four states viz. Bihar, Eastern UP, Jharkhand and West Bengal have a greater number of diesel engines than electric motors (per 1000 ha NSA).

Farm Power Availability in Eastern India

The total farm power availability in India in 2000-01 was at 1.35 kW/ha while the same in 2016-17 was at 2.03 kW/ha. However, in Eastern states the farm power availability had also increased significantly during the last 15 years. For example, in Bihar the power availability increased by whopping 250% i.e., from 0.8 kW/ha (2001) to 2.8 kW/ha (2017), owing to the initiative taken by state Government in the form of subsidies to various farm power machines, popularization of

Fig. 4 Spatial changes in tractor density in eastern region of India (2014-17)*



* Data of 10 districts were not available (Bihar: Bhabhua, East & West Champaran, Saran; Chhattisgarh: Bastar, Kawardha; Jharkhand: East & West Singhbhum; Odisha: North Cachar Hills; West Bengal: Kolkata)

farm machines, mechanization fair in each districts of Bihar. Similarly, farm power availability increased by 175%, 108% and 102% for Odisha, Chhattisgarh and Jharkhand, respectively (**Table 7**). **Fig. 6** shows the change in farm power availability of individual district of all the seven states during 2014-17.

There is accelerated fragmentation of land holdings in eastern India. For example, in Bihar the number of land holdings in marginal farmer category (<1 ha) increased from 84.18 to 91.21% during 2001-2016. This will lead to further increase in number of small and marginal farmers. Thus, for second Green Revolution to take place from Eastern region of India, small farm mechanization will be the key. There has been increase in tractor density in most parts of eastern region, however, such growth penetration was comparatively less in other farm implements. Thus, for a sustainable agricultural future, other farm implements, and not just tractors, need to be demonstrated and disseminated among the farmers in the region for improved mechanization. State Government's initiatives in the form of subsidies to various farm power machines, popularization of farm machines, mechanization fair in each district has resulted in increased mechanization in the eastern region. However, there is need to develop and popularize solar based technologies to reduce dependency on diesel fuel and ensure environmental sustainability.

Table 5 Status of electric motors in Eastern Region of India (2014-17)

States	No. of electric motors per 1000 ha net sown area		Percentage increase in Number of electric motors
	2014	2017	
Assam	1.2 (0.23)	1.3 (0.22)	2.11
Bihar	47 (17.7)	48.0 (16.32)	10.16
Chhattisgarh	73.8 (23.2)	79.6 (22.59)	7.78
Eastern UP	46.5 (17.0)	51.2 (16.78)	7.78
Jharkhand	5.6 (0.57)	6.0 (0.56)	7.78
Odisha	66.0 (24.7)	81.2 (27.37)	23.07
West Bengal	47.2 (16.6)	50.8 (16.16)	7.70
Eastern Region	48.4 (100)	53.7 (100)	10.95

(Data in parenthesis show the share of individual state in Eastern India)

Table 6 Status of diesel engine in Eastern Region of India (2014-17)

States	No. of diesel engine per 1000 ha net sown area		Percentage increase in number of diesel engines
	2014	2017	
Assam	0.4 (0.04)	0.7 (0.06)	70.0
Bihar	159.2 (32.10)	160.0 (30.18)	0.52
Chhattisgarh	10.7 (1.8)	11.3 (1.78)	1.78
Eastern UP	189.0 (36.90)	213.5 (38.98)	13.0
Jharkhand	23.1 (1.27)	26.6 (1.36)	15.20
Odisha	17.9 (3.58)	19.0 (3.55)	6.04
West Bengal	129.0 (24.32)	136.6 (24.08)	5.88
Eastern Region	90.44 (100)	96.7 (100)	6.93

(Data in parenthesis show the share of individual state in Eastern India)

Conclusions

There has been considerable increase in farm power availability on Indian farms during the last decade. The eastern region of India has also followed the similar trend. There has been decrease in dependency on draught animal power and increase in adoption of mechanical power across the states. Also, the adoption of electric motors in states like Bihar and Odisha has improved due to better availability of electricity. The preference of power tillers is more than tractors in Odisha. Jharkhand and Chhattisgarh have shown tremendous growth both in number of tractors as well as power tillers. However, out of the seven states only Bihar (2.80 kW/ha) and Eastern UP (2.67 kW/ha) has farm power availability more than the national average of 2.24 in 2017. Other eastern states should emulate

Fig. 5 Spatial distribution of electric motors and diesel engines per 1000 ha NSA in Eastern region of India in 2017

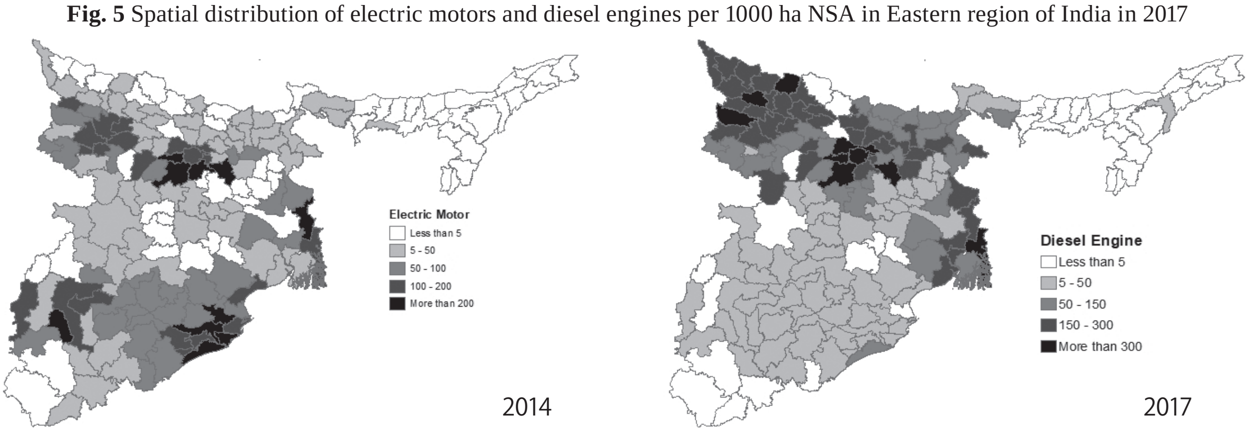


Table 7 Dynamics of Farm Power availability in Eastern region of India (2001-2017)

States	Farm Power availability (kW/ha)			Change during 2001-17 (%)
	2001	2014	2017	
Assam	0.80	0.87	0.99	23.8
Bihar	0.80	2.47	2.80	250.0
Chhattisgarh	0.60	1.02	1.25	108.3
Eastern UP	0.60	0.99	1.21	101.7
Jharkhand	0.60	1.442	1.65	175.0
Odisha	1.75*	2.27	2.67	-
West Bengal	1.25	1.62	1.87	49.6
Eastern Region	-	1.66	1.94	-
All India	1.35	1.84	2.24	50.4

*Data for Uttar Pradesh
Source: Srivastava (2006), Anonymous (2018), Mehta et al. (2019)

the schemes and provisions provided by State Governments of Bihar and Eastern UP. Small land holding is the major constraints in adopting farm powers and implements. After sales support for farm powers and implements are needed for timely repair and maintenance. Lack of after sales support is also a major deterrent in their adoption. Custom hiring centers should be promoted more in these states. The farm machinery bank may be established in low farm power availability region for machines suited to the cropping pattern of the region.

REFERENCES

Anonymous. 2017. Indian farm mechanization market. Indian council of food and agriculture. Pp-4. http://www.icfa.org.in/assets/doc/reports/IFMM.pdf (Accessed on 9th July 2020)

Anonymous. 2018. Final report on monitoring, concurrent evaluation and impact assessment of Sub-Mission on Agricultural Mechanization. Mechanization & Technology Division. Ministry of Agriculture & Farmers Welfare, India. Pp-254.

Anonymous. 2020. Samrudhi-Agriculture Policy: 2020. Department of Agriculture & Farmers' Empowerment. Government of Odisha. pp-67.

Bhatt, B. P., A. K. Sikka, J. Mukherjee, A. Islam and A. Dey. 2012. Status of agricultural development in Eastern India. Published by ICAR RCER, Patna, India. pp-519.

Gupta, N. 2016. Decline of Cultivators and Growth of Agricultural Labourers in India from 2001 to 2011. International Journal of Rural Management 12(2) 179-198.

Joshi, P. K. and M. T. Khan. 2017. Agricultural reforms: Why eastern India needs a Green Revolution. (https://www.financialexpress.com/opinion/agricultural-reforms-why-eastern-india-needs-a-green-revolution/885513/) (Accessed 6th July 2020)

Mehta, C. R., N. S. Chandel and T. Senthilkumar. 2014. Status, challenges and strategies for farm mechanization in India. Agricultural Mechanization in Asia, Africa and Latin America, 45(4): 43-50.

Mehta, C. R., N. S. Chandel, P. C. Jena and A. Jha. 2019. Indian agriculture counting on farm mechanization. Agricultural Mechanization in Asia, Africa and Latin America, 50(1): 84-89.

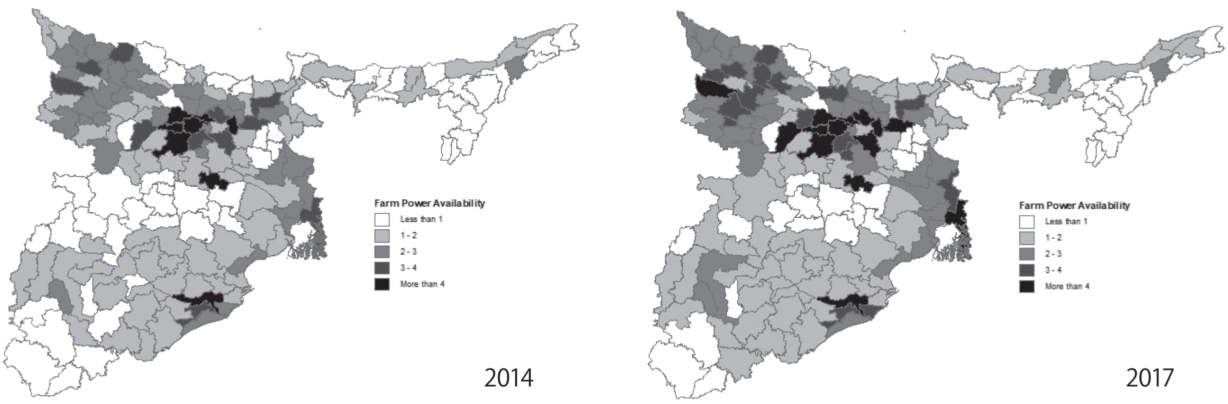
Mishra, S. 2019. Tractor sales growth pace hits three-year low in FY'19. https://auto.economictimes.indiatimes.com/news/automotive/farm-equipment/tractor-sales-growth-pace-hits-three-year-low-in-fy19/69093089 (Accessed 09th July 2020)

Singh, S. P., R. S. Singh and S. Singh. 2011. Sale trend of tractors and farm power availability in India. Agricultural Engineering Today, 35(2): 25-35.

Sundaram, P. K., B. Sarkar, D. K. Raghav, U. Kumar, A. P. Anurag and S. S. Mali. 2019.Constraints in adoption of modern farm machines by tribal farmers in Ramgarh District of Jharkhand. Journal of AgriSearch 6(3): 146-149.

■■

Fig. 6 Changes in farm power availability in eastern region (2014-17)



Mechanization Status in *Karaya* Gum Tapping and Scope for Improvement: A Review

by

S. C. Sharma
Senior Scientist
Mechanization and Process Engineering Division,
ICAR - Indian Institute of Natural Resins and Gums,
Ranchi (Jharkhand), INDIA

S. K. Pandey
Scientist (SG)
Mechanization and Process Engineering Division,
ICAR - Indian Institute of Natural Resins and Gums,
Ranchi (Jharkhand), INDIA

N. Prasad
Principal Scientist and Head
Mechanization and Process Engineering Division,
ICAR - Indian Institute of Natural Resins and Gums,
Ranchi (Jharkhand), INDIA

Abstract

Natural gums are among the important non timber forest products and are produced from a wide range of plants. *Karaya* gum is the dried exudate produced from *Sterculia urens* tree, which is an important raw material for textile, cosmetic, food, pharmaceutical and other industries. Gums are produced by exposing the gum ducts on the stem of the trees by making suitable incision. The existing tapping technique and devices are traditional, location specific, less efficient and time consuming. Tools and equipments developed for *karaya* gum tapping may be used to enhance productivity of the gum tappers, reduction in time of operation, drudgery and manpower requirement with increase in *karaya* gum production. Similarly, improved tapping technique and tools will minimize injury to the trees and help in sustainable production of gums with conservation of natural population of *karaya* trees. Increase in sustainable livelihood of rural and tribal people might be possible with adoption of scientific methods of *karaya* gum tapping to get remunerative prices of the products. The gum production systems need to be improved for efficient utilization of natural resource with higher yield and reduced manpower requirement. There is need to follow scientific methods of tapping and collection of the *karaya* gums in order to get remunerative prices of the products. Battery operated tools/equipments may be given preference in *karaya* gum tapping work especially in remote areas where electricity is a problem so that productivity of the person involved in karaya gum tapping work may be enhanced.

Keywords: Gum tapping, *Karaya* gum, Tools, Mechanization

Introduction

Natural Resins and Gums (NRGs) are produced by plants in the form of sticky exudates and nodules spontaneously. It is also collected by making incisions in the bark of the tree trunk by weaker sections of the society dependent on forests for their livelihood particularly tribal farmers in rural areas. NRGs sector is one of the most important sources of livelihood support of more than 50 million population inhabiting forest and sub forest areas and is a major source of employment. In India over 5 million tribal depend on Non-Wood Forest Products (NWFPs) for their employment and household income from the forests (Rawat and Jishtu, 2006). NRGs are non-toxic, biodegradable and eco-friendly for use in various industries. Gums are viscous secretion of some trees and shrubs that hardens on drying, are solids consisting of mixtures of polysaccharides (carbohydrates) which are either water-soluble or absorb water and swell up to form a gel or jelly when placed in water. Most of the NRGs are collected in small quantities by forest dwellers by adopting traditional tapping methods. Benefit mainly depends on the quality of the produce. NRGs industry can provide employment and a steady additional income to rural people and thereby stop their migration into the towns and cities. The existing NRGs tapping technique and devices are traditional and location specific. The techniques and devices which are in vogue are less efficient and time consuming and having problem in handling and its operation. Therefore, there is tremendous potential to develop the sector further.

Karaya gum is the dried exudates obtained from the stem and root of *Sterculia* tree, family *Sterculiaceae*. The gum is produced by genus *Sterculia* and is collected after tapping or blazing the tree or as natural exudates (Elkhalifa et al., 2010). It is also known as Indian tragacanth and obtained from *Sterculia urens* Roxburgh. Local name of *karaya* gum is *Gulu*, *Kadaya, Karaya*, *Katera*, *Kullo* and *Tapsi*. Globally, *karaya* gum trees are found in South Africa, Australia, Pakistan, Panama, Philippines, Indonesia, Senegal, Sudan and Vietnam. In India, major *karaya* gum producing states are Andhra Pradesh, Madhya Pradesh, Maharashtra, Gujarat, Odisha, Rajasthan, Tamil Nadu, Karnataka, Jharkhand and Chhattisgarh.

Karaya gum is used in several industries due to its low solubility in water and low cost but swells to many times its original volume (Mali et al., 2012). Gum *karaya* is used for many industries i.e., petroleum and gas, printing and textile, paper and pulp, leather and allied products, ammunition and explosives, electrical appliances, adhesives, confectionery, medicine, pharmaceuticals and cosmetics (Gautami and Bhat, 1992; Dikshith et al., 1984 and Kuruwanshi et al., 2017). India is the leader in gum *karaya* production and export in the world (Srivastava and Ray, 2015).

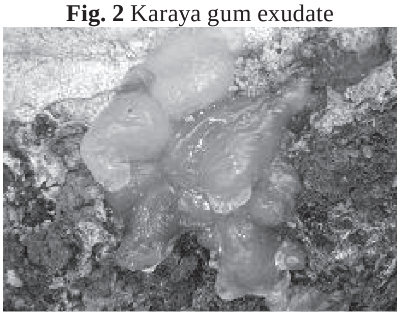
Fig. 1 Blaze made for *karaya* gum tapping

Annual production of *karaya* gum in India was approximately 100.35 tons during the year 2015-16. Export of gum during 2015-16 was 263,130.94 tons valued at Rs. 311,995.60 lakhs. Out of the total gum export during the year, 230.77 tons gum *karaya* was exported for Rs. 771.59 lakhs (Yogi et al., 2018). The paper discusses different techniques developed and adopted by previous researchers for *karaya* gum tapping from *Sterculia urens* trees and scope of improvement in it.

Traditional Method of *Karaya* Gum Tapping

There is some natural exudation of *karaya* gum but most gum is collected by tapping. Descriptions of the tapping slightly vary according to the source of the information, but all entail removal of sections of bark from the trunk of the tree. Guidance rules have been laid down by the Forest Research Institute, Dehradun, in India, but in practice the rules are not adhered to and the dimensions of the "blaze" are often exceeded. Tapping which involves deep and wide wounds to the tree to maximize gum yields is damaging to the tree, and this led to a ban on tapping by Indian Forestry Department in the 1980s.

Fig. 2 Karaya gum exudate



Karaya gum is commercially tapped through blazing, peeling or by making deep cut in the base of the tree trunk with an axe. The normal practice in Chhattisgarh and Madhya Pradesh for *karaya* gum tapping is by making a blaze with the help of an axe on the tree trunk (**Fig. 1**). During the survey, three types of blazings have been observed by Shaw et al. (2010) under *karaya* gum tapping. First type of blazing for tapping *karaya* gum involves making 2-3 blazes of around 10 cm × 20 cm size on the tree trunk at different places at a time and collection of the gum begins after 7-8 days. To continue the process of tapping further, another 2-3 or more blazes are made on the trunk of the tree. In the second type of gum tapping method, around 10-20 cuts are made on the tree trunk at a time and collection of gum start after 7-8 days. Similarly, to continue tapping, another 10-20 cuts are again made on the tree trunk immediate after gum collection. In third type of gum tapping technique, a big blaze is made on the tree trunk and collection of gum starts after 7-8 days (**Fig. 2**). In similar fashion another blaze is made after tapping gum from first blaze. Such method of tapping leads to girdling of tree (Sharma et al., 2016a).

Indian experience exhibits that tapping is confined to trees with a minimum of 28.7 cm diameter at breast height (DBH) and the initial size of the blaze is limited to 15 cm tall, 10 cm wide and 0.5 cm deep. The tapping technique is accomplished by removal/incision of bark from the trunk with special tapping tool. Sixteen successive visits can be made to the tree at two-week intervals, removing a further

2 cm high section of the bark above the previous one at each visit, and leading to a maximum depth of the blaze of 2.5-3.0 cm. An additional blaze can be worked for every 16 cm DBH increment above 28.7 cm DBH, providing sufficient space is left between adjacent blazes. Tapping is best done during the hot season to maximize yields (Coppen, 1995). The gum begins to exude immediately and the exudation continues for several days. The maximum amount of exudation occurs within the first 24 hours (Sao, 2012). The gum is in the form of huge irregular tears. The best quality gum is collected during April, May and June. During this time, as the weather gets warmer the yield increases (Anonymous, 2007a).

Due to the enormous socioeconomic importance *karaya* gum products, in India, researches are conducted by different researchers to improve the tapping techniques (Shiva et al., 2006) and they have designed special tools for tapping. According to Shiva et al. (2006) the newly designed tools have controlled the optimum depth of the blazes/incisions on the trees that may help to obtain optimum quantity of gum without causing damage to the trees. Average yield per tree ranges from 1-5 kg and 4.3-7.2 kg during one year/season according to Coppen, 1995; Anonymous, 2007b and USAID, 2005, respectively. It is hoped that the newly designed tools will prove useful in obtaining the sustained production of gums without causing mortality of trees. In India, as *karaya* gum is vital for tribal economy with respect to its trade value, there is a pressing need to develop a scientific and sustainable tapping method to increase the yield and quality and ensure the survival of the tapped trees (Shiva et al., 2006).

Tapping of *karaya* gum from gum yielding trees (*Sterculia* urens) is done by blazing and stripping off the tree bark. Maximum amount of gum is produced within first 24 hours of blazing and continued for few days. It solidifies in the form of gum tears when exposed in the environment. *Karaya* gum can be tapped throughout the year except during rainy season as is either washed off and does not get dried easily and also poor in quality i.e., darker in color with high moisture content and impurities. Though the gum exudes from the blazes all the year around; the flow is more copious in the hot weather and best quality gum is produced during January to June. Blazing of the trees has an important bearing on the tree health and heavy tapping is believed to impair the seed fertility and thus regeneration. Therefore, tapping should be done with the least possible harm to the trees. Precaution should be taken while tapping gum, the *karaya* gum tree should be of at least 3 ft. in girth and blazing should be confined to main stem above 3 ft. from the ground level. The blazes of the rows should be alternate and depth of the blaze should not exceed ½” till second layer is exposed and each blaze should be a semi circle with 6” wide base. In the 2nd and 3rd year, tapping can be continued by extending the 1st year blaze 5 cm above the previous year’s treated area and old wounds should not be reopened. In order to keep the longevity of the tree and for better quality of gum, tapping should not be done continuously and trees should be given long periods of rest before re-tapping so that the blazed portion gets enough time to heal which takes about 60 days after tapping and resume normal activity. Excessive tapping of the tree may also deteriorate the

Table 1 Comparative description of recommended methods of gum tapping from *Sterculia urens* trees

Karaya tapping methods aspect	Method adopted by Damoh & Jabalpur Forest Departments	Method proposed by FRI, Dehradun
Appropriate tree girth	90-135 cm	> 90 cm
Number of blazes/tree at a time	2 blazes in case of 90-135 cm girth trees	1 blaze for a tree of 90 cm girth
	3 or 4 blazes in trees with girth > 135 cm	An additional blaze for every increment of 50 cm of girth
Position of the blaze	Not specified	Not lower than 30 cm from the ground level
Initial size of the blaze	15 cm long and 7.5 cm wide	15 cm long and 10 cm wide
Maximum size of the blaze	45 cm long and 25 cm wide	47.5 cm long and 12.5 cm wide
Blazing instrument characteristics and its handling	Should be sharp but do not hammer the bark lest the pores should get compressed and closed	Sharp instrument
Depth of initial blaze	Should just penetrate the wood	Maximum 0.5 cm deep in wood cambium
Freshening	Only 1.5-3 mm bark thickness should be cut and removed each time	Each time, 2 cm bark above the initial blaze should be removed; the blaze depth should not exceed 3 cm; freshening to be done fortnightly
Tapping cycle	4-5 years	For continuous tapping, the tree can be divided in to 3 zones; 1 zone is tapped/season; hence a 3-5 year cycle is followed
Proposed yield	75-150 kg/annum per 100 blazes; in case of a tree of 90-135 cm girth – 1.5 to 3 kg/annum	75-100 kg/annum per 100 blazes; in case of a tree with 2 blazes and of 90-135 cm girth, gum yield would be 2.5 to 5 kg/annum

gum quality. The yield has increased about 20 to 30 times over the control and about 10 times more than the traditional tapping methods used by the local people (Kumar, 2016). There was a marked difference in the yield among individual trees, presumably due to heterozygosity.

The best quality gum is collected during April-June i.e., before commencement of monsoon. As the weather becomes warmer, the gum yield and quality improve. Collection may be repeated after the monsoons in September, although this gum may be darker in color and lower in viscosity. When trees are incised or blazed, gum begins to flow immediately, and exudation continues for several days. The maximum amount of exudation occurs within the first 24 hr. The yield of the gum from matured trees is estimated at 1 to 4.5 kg per tree per season. The average tree can be tapped five times during the lifetime (Sao, 2012).

Scientific Tapping Method

Several agencies have explored methods of tapping the gum tree to maximize gum yields (both qualitatively and quantitatively) without killing the precious tree resource. Two of the improved methods of *karaya* gum tapping, one adopted by the Damoh and Jabalpur Forest Departments and another evolved by the Forest Research Institute (FRI) Dehradun are summarized in **Table 1** (Anonymous, 1973; Fri, 1972 and Bhattacharya et al., 2003).

Table 2 Methodology of *karaya* gum tapping developed by Kovel Foundation, Visakhapatnam in collaboration with Girijan Co-operative Corporation, Visakhapatnam

Steps	Procedure
1	Select a suitable karaya tree for gum tapping having 90 cm or more girth at waist height whose trunk matches the entire arms-reach of a normal individual.
2	Clean the debris and loose bark from tree trunk using leaves or a piece of cloth followed by clearing the ground area within 100 cm radius near the selected tree for hindrance free working of gum tapper.
3	Develop a 12-15 cm horizontal incision on the tree trunk at waist height using sharp knife (**Fig. 4**) and join the ends of incision by another, higher, crescent shaped incision on the tree trunk (**Fig. 3**). **Fig. 3** Blaze formed for *karaya* gum tapping using sharp knife 
4	Deepen the two incisions with sharp knife up to about 3.0 cm deep and do not remove the bark.
5	Beat the bark bounded by the incisions using mallet or blunt end of sharp knife/axe till the bark becomes soft and pulpy and leave it attached with tree trunk for a fortnight.
6	Remove the dried and died beaten portion of bark from incisions by hands or using knife after a fortnight and peel off a thin layer of live bark from the top crescent portion to initiate gum exudation.
7	Clean the area in and around the blaze using a piece of cloth and attach a small polythene sheet to the face of the blaze using thorns so that oozed gum from the crescent incision should drip on the polythene in the form of large, irregular tears and leave the polythene on the tree trunk for at least two days.
8	Return on the 3rd day with the sharp knife and a bamboo basket hanging from the elbow by a coir rope and remove thorns from lower end of polythene attached to the blaze by holding polythene alongwith collected gum carefully in one hand followed by removing thorns from upper end of the polythene. Cut the gum stream to disconnect the gum collected on the polythene from the flows oozing from the trunk using knife by other hand and place the polythene with its gum in the bamboo basket carefully. After removal of gum from blaze, a new and clean polythene sheet should be attached for further collection of gum from same blaze. Freshen the crescent shaped blaze by slicing a very thin layer from it, using knife, if the gum flow has ceased.
9	Repeat the step no. 8 every 3rd day, till the blaze is too high on the trunk for tapper to reach easily which takes 3 years usually. Start preparing a new blaze, if blaze is too high from the reach of the tapper followed by developing only one blaze per tree, at a time.
10	New blaze should be made diametrically opposite the first blaze followed by Steps 2 to 9 for another 3 years. Third blaze may be made on one side between the first and second blaze developed and similarly, fourth blaze would be developed on the side opposite to the 3rd blaze on the trunk. After a karaya tree has been tapped for 12 years continuously in this way, the wound from the first blaze should have healed completely and the trunk on that side is ready for tapping again.
11	Gum bearing polythene sheets are inverted and emptied on to a larger polythene sheet that has been spread over a bamboo-mat on a raised platform. This platform should be at least of waist height and constructed in an open, dust-free and sunny space to allow the gum to dry quickly. Pieces of bark, leaves or other extraneous material should be removed from the semi-solid gum using forceps. The gum pellets are than sun dried until they become brittle.
12	Dried gum is then sorted into grades on the basis of color and amount of visible impurities.
13	Dried gum should be stored in clean and airtight polythene bags ready for the market.

Semi Circular Blazing Technique of *Karaya* Gum Tapping

A semi-circular blazing technique for *karaya* gum tapping was developed by Kovel Foundation, Visakhapatnam (Andhra Pradesh) in collaboration with Girijan Co-operative Corporation, Visakhapatnam (Andhra Pradesh) for scientific tapping of *karaya* gum from *Sterculia urens* tree using specially devised sharp knife (**Fig. 4**) to make incisions on the tree trunk. Kovel's technique not only incorporates the basic principles followed in the earlier improved methods developed for *karaya* gum tapping from *Sterculia urens* trees but also permits continuous, sustainable tapping of high-quality gum. Methodology of *karaya* gum tapping developed by above organizations as described by Bhattacharya et al., 2003 are detailed in **Table 2**.

Tools and Material Requirement for *Karaya* Gum Tapping from *Sterculia urens* Trees Through Semi Circular Blazing Technique

Under mentioned tools and materials (**Table 3** and **Fig. 4-9**) required for *karaya* gum tapping from *Sterculia urens* trees through semi circular blazing technique developed by Koval Foundation in collaboration with Girijan Co-operative Corporation, Visakhapatnam (Andhra Pradesh).

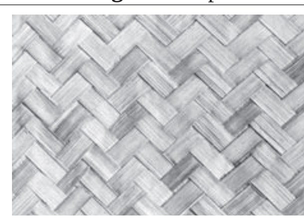
Steps for *karaya* gum tapping technique developed and standardized by Kovel Foundation, Visakhapatnam in collaboration with Girijan Co-operative Corporation, Visakhapatnam (Andhra Pradesh) depicted as pictorial representation in **Fig. 10**.

Mechanization in Blazing Technique of *Karaya* Gum Tapping

A blazer to control the size and depth of blaze for sustainable *karaya* gum production and conservation of karaya gum producing trees (**Fig. 11**) was developed by researchers from Indira Gandhi Krishi Vishwavidyalaya, Raipur (Chhattisgarh) under All India Network Project on Harvesting, Processing and Value Addition of Natural Resins and Gums. The developed blazer was found suitable for making blaze on *karaya* tree (**Fig. 12**) for gum tapping (Patil et al., 2018).

Shiva et al., 1994 developed a newly designed improved gum tapping tool (**Fig. 13**) and utilized in the gum tapping experiments from *Acacia nilotica* and *Prosopis juliflora* respectively and observed that tool developed have controlled the optimum depth of the blazes/incisions on the trees that may help to obtain optimum quantity of gum without causing damage to trees. Developed tool was found successful in the case of Babool and Prosopis gum tapping experiments conducted at Meerut and Mathura Forest Division in Uttar Pradesh. They reported that developed tool likely to prove beneficial in the tapping of commercially important gums i.e., *karaya* gum from *Sterculia urens*/ *Sterculia villosa*, jhingan gum from *Lannea coromandelica*, ghatti gum from *Anogeissus latifolia*, semla gum from *Bauhinia retusa* trees etc. The developed tool has sharp edged

Table 3 Tools and Materials required for karaya gum tapping and their purpose

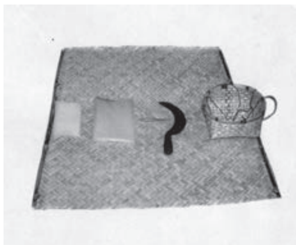
Purpose	Tools and Material	Purpose	Tools and Material
Making blaze/incision on tree trunk for gum tapping	 **Fig. 4** Sharp knife	Fixing polythene on the developed blazes for collection of exudated karaya gum and for easy collection	 **Fig. 5** Small polythene
Transportation of collected karaya gum from field to storage area safely	 **Fig. 6** Bamboo basket	Removal of impurities from collected karaya gum	 **Fig. 7** Forceps
Covering karaya gum kept over bamboo mat for drying at elevated height from ground	 **Fig. 8** Large polythene	Drying of collected karaya gum	 **Fig. 9** Bamboo mat

rectangular chisel at one end of size 10 cm length, 4 cm height and 4 cm depth particularly for gum tapping from *Sterculia urens* trees made of mild steel sheet and a rectangular piece of mild steel is fixed at another end having length 15 cm, width 4 cm and height 4 cm respectively. For making blazes on the tree trunk for gum tapping, the developed tool was required to be placed at desired position on the tree trunk and hammered. The edge of the tool was so designed that the chisel does not go more than 5.0 cm in wood just below the Cambium.

Sharma and Prasad, 2013 conducted experiment for *karaya* gum tapping from *Sterculia urens* trees growing in Taimara Valley about 25 km from ICAR – Indian Institute of Natural Resins and Gums, Ranchi on Ranchi – Jamshedpur National Highway 33 utilizing semi-circular blazing technique of *karaya* gum tapping developed and standardized by Koval Foundation, Visakhapatnam in collaboration with Girijan Co-operative Corporation, Visakhapatnam (Andhra Pradesh).

Fig. 10 Steps of karaya gum tapping through semi circular blazing


(i) Selection of suitable tree for gum tapping


(ii) Tools and material required for karaya gum tapping


(iii) Method of making blaze


(iv) Semi circular blazing


(v) Hammering the cut bark for removal


(vi) Bark after hammering


(vii) Separation of hammered bark


(viii) Installation of polythene sheet


(iv) Extraction of karaya gum


(x) Karaya gum transportation

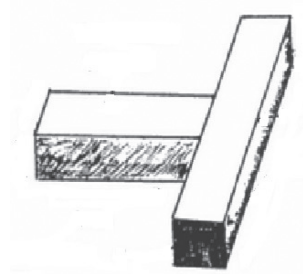

(xi) Removal of impurities from collected gum


(xii) Drying of exudated karaya gum

Fig. 11 Blazer for making blaze on *karaya* tree for gum tapping

Fig. 12 Blaze developed on the tree trunk using blazer

Fig. 13 Improved gum tapping tool



After one month of treatment, exudated gum was collected and the blaze of each tree were refreshed by removing thin bark of the blaze for opening the gum ducts for further gum exudation and the freshening process continued throughout the experiment duration with monthly interval. It was observed that gum exudated from the trees round the year but exudation was more during hot weather condition. Minimum and maximum gum yield was 304.88 g and 1,310.48 g for trees having diameter 0.56 and 0.70 m respectively. Physical damage in the trees was worked out to be 91.16 cm^2 on area and 231.55 cm^3 on volume basis, respectively.

Gum Inducer Technique of *Karaya* Gum Tapping

A simple and safer technique of tapping with substantial increase in the yield is being developed using ethephon (2 – chloro ethyl phosphonic acid) to enhance gum yield and faster wound healing. After 45 days a thick wound tissue will develop at the injured region and almost replaces the damaged tissue when using this method. The wound is completely healed in 60 days after tapping. While using this method the yield increases by approximately 20 to 30 times more than the control. There is also a marked difference in the yield among individual trees, presumably owing to heterozygosity. The systematic and scientific tapping technique using ethephon as a stimulating agent for gummosis or gumresinosis could ensure substantial improvement and sustainable production of these materials (Balakrisnan, 2003).

Scientific technique of gum arabic tapping known as "gum inducer technology" developed by researchers from ICAR – Central Arid Zone Research Institute, Jodhpur (Rajasthan) under ICAR – All India Network Project on Harvesting, Processing and Value Addition of Natural Resins and Gums as detailed below was adopted by researchers from Indira Gandhi Krishi Vishwavidyalaya, Raipur (Chhattisgarh) and ICAR – Indian Institute of Natural Resins and Gums, Ranchi (Jharkhand), respectively for *karaya* gum tapping from *Sterculia urens* trees.

To produce and enhance gum arabic production from Acacia senegal tree, a small size hole of 12 mm diameter and 25 mm deep with 45° inclination towards inner side is made on the tree trunk about 450-500 mm above the ground using manually operated drill (**Fig. 14**) and mixture of sulphuric acid (H_2SO_4) and ethephon is injected in the hole (780 mg/4 ml) through disposable syringe (**Fig. 15**) followed by patching the hole with wet clay soil or bee wax (**Fig. 16**) after treatment to make the hole air tight for enhancing gummosis process utilizing ethylene gas produced inside the hole.

Sharma and Prasad, 2013 conducted experiment for *karaya* gum tapping from *Sterculia urens* trees naturally growing in Taimara Valley about 25 km from ICAR – Indian Institute of Natural Resins and Gums, Ranchi on Ranchi – Jamshedpur National Highway 33 utilizing gum inducer technique developed for gum arabic tapping from *Acacia senegal* trees by researchers from ICAR – Central Arid Zone Research Institute, Jodhpur (Rajasthan) under ICAR – All India Network Project on Harvesting, Processing and Value Addition of Natural Resins and Gums. After one month of treatment, exudated gum was collected and hole of each tree were rebored up to the same depth as made earlier for opening the clogged gum ducts for further gum exudation and the process was continued throughout the experimentation at monthly interval. It was observed that gum exudated from the trees throughout the year but exudation was higher during hot weather condition. Minimum and maximum gum yield was 1,189.10 g and 4,285.65 g, respectively for trees having diameter 0.56 and 1.15 m. Physical damage in the trees through gum inducer technology was worked out to be 1.27 cm^2 on area and 12.86 cm^3 on volume basis.

Fig. 14 Making hole with hand drill

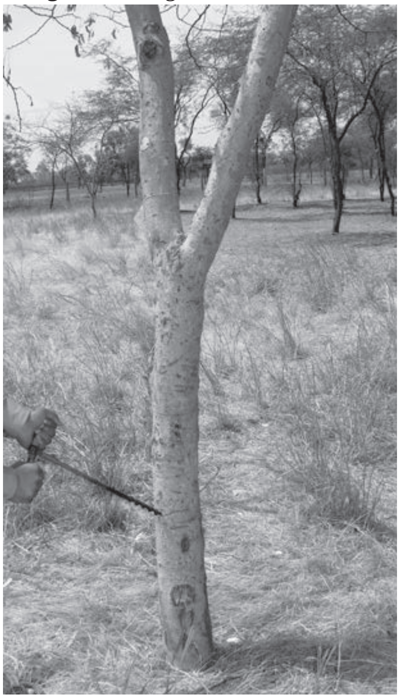


Fig. 15 Injecting gum inducer

Fig. 16 Covering the hole by moistened clay

The gum inducer technology was found better for *karaya* gum tapping from *Sterculia urens* trees in Jharkhand region with 17 times less damage to trees on volume basis and about 200% higher gum yield compared to semi circular blazing technique of *karaya* gum tapping.

Nair, 2003 conducted experiment on 15 trees of *Sterculia urens* in the Ghati village near Gwalier Highway No. 3 to find out optimum concentration of ethephon to induce maximum production of gum with minimum injury to the tapped trees. Using a specially devised knife, holes each of 5 mm diameter and 2-3.5 cm depth based on the thickness of the bark were made on the tree trunk 20 to 30 cm distance at 100 cm above the ground level. The holes were angled towards the base of the tree to prevent the backflow of the introduced solutions. One hole in each tree was maintained as control injecting distilled water and the rest were treated with ethephon. One milliliter of ethephon containing 190/285/390 milligrams of active substance (one ml of distilled water for control) was dispansed in to each hole. Five trees were used for each concentration. The first collection of gum produced in the control and treated holes were made after 15 days. The succeeding 3 collections were done after every 10 days. It was noticed that the trees treated with 285 milligram of active substance of ethephon have yielded highest amount of gum and therefore this concentration was used for further experiments.

The tapping experiments were repeated at Ghati village in Madhya Pradesh and Cheedipalem in Andhra Pradesh. Fifteen trees of various sizes and ages were selected for the study at both the sites. The trees were tapped in March, May and November 1995 in Ghati village using 285 mg of active substance to understand the seasonal variation in the gum yield. The tapping of trees at Cheedipalem were done in February and May in 1996. The *karaya* trees are tapped by the tribal people with the help of Girijan Co-operative Corporation in Andhra Pradesh. The yields from the traditional tapping method and the method using ethephon were compared. The tribal people remove 50 to 55 cm length of bark across the trunk with a sickle and collect the gum as tears or as irrigular fragments. The tapped trees often fail to regenerate after some years. The trees were tapped throughout the year except in the rainy season. Study revealed that ethephon treatment resulted in the increase in gum production of about 40 to 85 times more than the control. The harvest from the ethephon treated trees was of high quality gum. The gum started oozing out of the holes within 3 to 5 hours and gets hardened when comes in contact with environment. The control holes produced negligible amount of gum. It was found that the damaged tissues of the ethephon treated holes were nearly replaced with wound tissue after 45 days. The injury was completely healed after 2 months. Results of the tapping done at Ghati village of Madhya Pradesh in the year 1995 shows highest amount of gum produced in May and least amounts in November. The tapping experiments conducted in Cheedipalem, Andhra Pradesh also shows copious gum production in the summer month. The yield of gum when tapped using ethephon was about 10 times more than the yield when tapped using traditional method which ensures minimum injury to the trees so that the tree is regenerated easily, thus guaranteeing sustainable production of gum. The injury made by the traditional tapping is very large (50 to 55 cm long). The gum exudation in *karaya* tree is highest in April - May, the exudation is about 10 times more than the production in November. Therefore, it is suggested that *karaya* gum tapping for commercial purpose be done only during March to May and the trees may be given rest in the remaining part of the year. This will ensure regeneration of the tapped trees, sustainable supply of *karaya* gum with good economic return.

Fig. 17 Battery operated drill

Fig. 18 Drill attachment/bit

Mechanization in Gum Inducer Technique of *Karaya* Gum Tapping

The gum inducer technique developed for gum arabic tapping by researchers from ICAR – Central Arid Zone Research Institute, Jodhpur (Rajasthan) under ICAR – All India Network Project on Harvesting, Processing and Value Addition of Natural Resins and Gums was mechanized using battery operated drill instead of manually operated drill (**Fig. 17**) to enhance the productivity of gum tappers. It can drill holes up to a diameter of 18 mm in wood. The drill can be operated with battery and drill attachment/bit (**Fig. 18**) supplied by the company. This drill can be operated for long duration in remote area with the backup of a charged battery which may be replaced as per requirement (Sharma et al., 2016b).

Prasad et al., 2012 reviewed the

work carried out for mechanization of *karaya* gum tapping and reported use of axe (**Fig. 19**) and blazing knife (**Fig. 20**) for making blaze in blazing method of *karaya* gum tapping. They further reported use of hand and battery-operated drill (**Fig. 21** and **Fig. 22**) for making hole in gum inducer method of gum tapping using different gum inducers.

An investigation was carried out by Kuruwanshi et al., 2017 at former Central Government Forest Division, Biladi at Tilda block of Raipur (Chhattisgarh) during year 2015 and 2016. The experiment was laid out with three replication and six treatments i.e., distilled water as control (T_1), different ethephon concentration (T_2 - 2.34%, T_3 - 3.12%, T_4 - 3.9%) and Indole Acetic Acid (T_5 - 400 ppm, T_6 - 800 ppm) for potential gum production from *Sterculia urens* Roxb. Gum inducer technology developed by researchers from ICAR – Central Arid Zone Research Institute, Jodhpur (Rajasthan) under ICAR – All India Network Project on Harvesting, Processing and Value Addition of Natural Resins and Gums for gum arabic tapping was utilized for *karaya* gum tapping from *Sterculia urens* trees with distilled water and different concentrations of ethephon and IAA. During the period of experiment only two times 4 ml gum enhancer was introduced in treated trees in the month of March and May, respectively. It is observed that gum exudation in form of tears begin after 7-10 days of treatment (**Fig. 22**). Maximum rate of gum exudation observed in month of May during the year 2015 (440.33 g) and 2016 (530.1 g) followed by April and March and minimum rate of gum exudation was observed in June for the year 2015 and 2016. Similar enhanced gum arabic production of 0.8-0.90 kg per tree using 4 ml containing 960 mg active substance in the month of April/May also reported by (Bhatt and Mohan Ram, 1990 and Harsh et al., 2013). It was concluded that application of 3.9% concentrated ethephon was significantly superior for *karaya* gum production during 2015 (717.05 g) and 2016 (777.45 g) followed by 3.12% and 2.34%. Rate of gum exudation using IAA @ 800 ppm was minimum during both the years. Similar enhancement in *karaya* gum production without any apparent ill effect on the health of the tree through injecting ethephon (4 ml) in the tree trunk of *Sterculia urens* trees during March and May also reported by Gupta et al., 2012 and Babu and Menon, 1989. Average quantity of gum exudation was highest for 3.9% concentration of ethephon followed by 3.12% and 2.34% compared with control. Similar increase in gum production with application of ethephon also reported by Sharma and Prasad, 2013.

Prasad et al., 2012 reported that researchers from Indira Gandhi Krishi Vishwavidyalaya, Raipur centre of ICAR – All India Network Project on Harvesting Processing and Value Addition of Natural Resins and Gums conducted experiment on *karaya* gum tapping from *Sterculia urens* trees located at Kurrabhata village of Gariaband (Chhattisgarh) by injecting ethephon during May - June, 2010 (**Fig. 23**). On each tree 4 holes of 6 mm diameter and 5 cm deep were made with the help of manually operated drill followed by injecting 1 ml ethephon in each hole with the help of disposable syringe and 1 ml distilled water as control. Researchers from the centre on *karaya* gum at IGKV, Raipur under Network Project on HPVA of NRG concluded that mean gum yield was 320 g per tree with ethephon, whereas in control gum production was negligible. Maximum and mini-

Fig. 19 *Karaya* gum tapping using axe

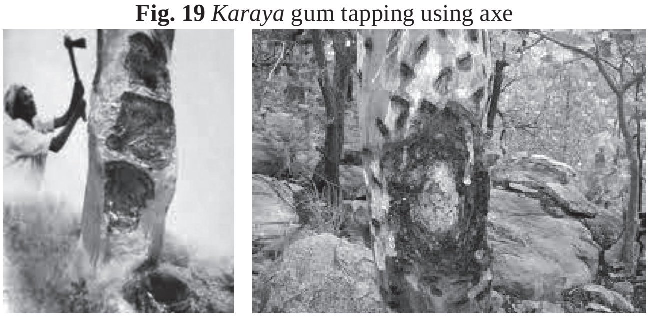


Fig. 20 Use of blazing knife for making blaze in karaya tree for gum exudation

Fig. 21 Use of hand drill for making hole in karaya tree for injecting gum inducer

mum gum production was found to be 650 g and 10 g respectively, from trees having girth 500 cm and 76 cm. They recommended that gum inducer technique of gum tapping from *Sterculia urens* trees showed least damage to the tree under gum tapping experiment therefore, the technique need to be promoted among gum pickers (Anonymous, 2011).

Effect of Tapping Technique on *Karaya* Gum Yield

Sharma and Prasad, 2013 conducted experiment on nine trees of *Sterculia urens* for *karaya* gum tapping growing in Taimara Valley about 25 km from ICAR – Indian Institute of Natural Resins and Gums, Ranchi on Ranchi – Jamshedpur National Highway 33.

Fig. 23 Karaya gum exudation using gum inducer (ethephone)

Out of nine trees, three trees were used for gum tapping through semi circular blazing developed and standardized by Koval Foundation, Visakhapatnam in collaboration with Girijan Co-operative Corporation, Visakhapatnam (Andhra Pradesh) for *karaya* gum tapping and six trees by gum inducer technique using ethephon developed by researchers from ICAR – Central Arid Zone Research Institute, Jodhpur (Rajasthan) under ICAR – All India Network Project on Harvesting, Processing and Value Addition of Natural Resins and Gums for gum arabic tapping from *Acacia senegal*. It was observed that gum started oozing out after 4 hours in treated holes in gum inducer technique and immediately in case of semi-circular blazing technique and mean *karaya* gum collection was found to be 753.68 g in cases of semi-circular blazing technique while 2,307.16 g for inducer technology during the experimentation period. Nair et al., 1995 also reported that ethephon enhances gum formation and wound healing in *S. urens*. It was also found that gum production was higher in case of inducer technology over semi-circular blazing almost in all the months during the duration of investigation. Inducer technology was found better for *karaya* gum tapping from *Sterculia urens* trees in Jharkhand region with 17 times less damage to trees on volume basis and about 200% more gum production compared to semi circular blazing technique (Sharma et al., 2018).

Conclusions

The gum production systems need to be improved for efficient utilization of natural resource with higher yield and reduced manpower requirement. Increase in sustainable livelihood of rural and tribal people might be possible with adoption of scientific methods of *karaya* gum tapping to get remunerative prices of the products. Tools and equipments developed for *karaya* gum tapping may be used to enhance productivity of the gum tappers, reduction in time of operation, drudgery and manpower requirement with increase in *karaya* gum production. Wireless/battery operated tools/equipments may be given preference in *karaya* gum tapping work especially in remote areas where electricity is a problem so that productivity of the person involved in *karaya* gum tapping work may be further enhanced.

Acknowledgement

The authors express their sincere thanks to Dr. K. K. Sharma, Director, ICAR – Indian Institute of Natural Resins and Gums, Ranchi for constructive suggestions and technical guidance provided in preparation of the manuscript. Authors are also thankful to Principal Investigators of different cooperating centers under All India Network Project on Harvesting, Processing

Fig. 22 Gum exudation in karaya after gum inducer treatment

Use of battery operated drill for making hole in karaya tree for injecting gum inducer | Gum inducer injection using syringe | Gum exudation in gum inducer method

and Value Addition of Natural Resins and Gums for their support in providing technical information related to mechanization in gum production. Financial support provided by Indian Council of Agricultural Research, New Delhi for the All India Network Project on HPVA of NRG is thankfully acknowledged.

REFERENCES

Anonymous. 1973. *Karaya* Gum from *Sterculia urens* Roxb. Industrial Series No. 7, Forest Research Institute, Dehradun.

Anonymous. 2007a. Krystal colloids. Processors. Manufactures. Exporters. http://www.krystal-colloids.com/karaya.html.

Anonymous. 2007b. Willy Benecke. Import. Export. whole sale. Gum *karaya* (*Sterculia* Gum). http//www.WillyBeneckegumkaraya.htm.

Anonymous. 2011. Annual Report, ICAR – Network Project on Harvesting, Processing and Value Addition of Natural Resins and Gums (Centre on Gum *Karaya*), Directorate of Research Services, Indira Gandhi Krishi Vishwavidyalaya, Raipur (CG).

Babu, A. M. and A. R. S. Menon. 1989. Ethephon induced gummosis in Bombaxceiba L. and *Sterculia urens* Roxb. Indian Forester, Vol. 115 (1): 44-47.

Balakrisnan, N. 2003. Sustainable utilization of gum and resin by improved tapping technique. Seminar proceedings harvesting of non-wood forest products.

Bhatt, J. R., M. N. B. Nair and H. Y. Mohan Ram. 1989. Enhancement of oleo-gumresin production in Commiphora wightii by improved tapping technique. Current Science, Vol. 58: 349-357.

Bhattacharya, P., B. Joshi and A. F. Hayat. 2003. An improved method of tapping gum Kullu (*Sterculia* urens). Forests, Trees and Livelihoods, Vol. 13 (2): 187-196.

Coppen, J. J. W. 1995. Gums, resins and latexes of plant origin. Non-Wood Forest Products – 6, Food and Agriculture Organization of the United Nations, Rome. 1- 142 pp.

Dikshith, T. S. S., R. B. Raizada, R. B. Misra and K. Srivastava. 1984. Toxicological evaluation of *karaya* gum; acute and subacute oral toxicity in rats. J. Biosci. Vol. 6: 147-153.

Elkhalifa, A., A. Wadoud and El Faith Ahmed Hassan. 2010. Characterization of *Sterculia* setigera gum (gum *karaya*) in Sudan. University of Africa J. of Science, Vol. 1 (1): 18-26.

Fri. 1972. Indian Forest Utilization, Forest Research Institute, Dehradun, 722-723 pp.

Gautami, S. and R. V. Bhat. 1992. A monograph of gum *karaya*. Hyderabad, India: National Institute of Nutrition, ICMR.

Gupta, R., S. Patel, P. Katiyar and R. K. Modi. 2012. Harvesting, Processing and Value Addition of Natural Resin and Gum. Directorate of research services, Indira Gandhi Krishi Vishwavidyalaya, Raipur (CG).

Harsh, L. N., J. C. Tewari, H. A. Khan and M. Ram. 2013. Ethephon-induced gum arabic exudation technique and its sustainability in arid and semi-arid regions of India. Forests, Trees and Livelihoods, Vol. 22(3): 204-211.

Kumar, V. 2016. Gum *karaya* (*Sterculia urens* Roxb.): A potential gum tree. Van Sangyan, Vol. 3 (10): 34-39.

Kuruwanshi, V. B., P. Katiyar and S. Khan. 2017. Scientific Approaches of Gum Tapping in Gum *Karaya* (*Sterculia urens* Roxb.) for High Gum Production. Int. J. Curr. Microbiol. App. Sci, Vol. 6(8): 3366-3374.

Mali, Y. N., S. P. Pawar, N. A. Gujarathi, B. R. Rane and S. R. Bakliwal. 2012. Applications of Natural Polymers in Sustained Release Drug Delivery System: A Review. Pharma Science Monitor, Vol. 3 (4): 3314-3335.

Nair, M. N. B. 2003. Gum tapping in *Sterculia urens* roxb. (*sterculiaceae*) using ethephon. Sustainable Production of Wood and Non-Wood Forest Products, Proceedings of the IUFRO Division 5, Research Groups 5.11 and 5.12, (Eds. Ellen M. Donoghue, Gary L. Benson, and James L. Chamberlain) Rotorua, New Zealand, 120 pp.

Nair, M. N. B., K. R. Shivanna and H. Y. Mohan Ram. 1995. Ethephon enhances *karaya* gum yield and wound healing response: A preliminary report. Current Science, Vol. 69: 809-810.

Patil, S. K., R. K. Bajpai, K. L. Nandeha, T. Chowdhury, H. Pathak, S. K. Dwivedi, G. L. Sharma, D. Gauraha, R. M. Savu, P. S. Pisalkar, D. Jha and S. K. Joshi. 2018. Annual Report 2017 - 18 (APR), Pub. By Univ. Technical Cell. Acc. No.: IGKV/Pub./2018/AR 2017 -18.

Prasad, Niranjan; K. R. Sharma, J. C. Tiwari, Rajeev Gupta and Moni Thomas. 2012. Mechanization of natural gum and resin tapping. Journal of Non – Timber Forest Products, Vol. 19(4): 279-289.

Rawat, R. S. and Vaneet Jishtu 2006. Non – Timber Forest Produces From Western Himalayan Forests. Journal of Non-Timber Forest Products, Vol. 13(3): 161-165.

Sao, K. P. 2012. Physico-chemical properties of some Indian plant gums of commercial importance. Bulletin (Technical) No. : 01/2012, ICAR – Indian Institute of Natural Resins and Gums, Namkum, Ranchi, 1-64 pp.

Sharma, S. C. and N. Prasad. 2013. Comparison of Gum Tapping Techniques for Gum *Karaya* – A Gum of Commercial Importance. Journal of Non-Timber Forest Products, Vol. 20(3): 165-170.

Sharma, S. C., N. Prasad, S. K. Pandey and S. K. Giri. 2016a. A

Review on Status of Gum Tapping and Scope for Improvement. Agricultural Mechanization in Asia, Africa, and Latin America, Vol. 47 (3): 68-75.

Sharma, S. C., N. Prasad, S. K. Pandey and Ranjit Singh. 2018. Mechanization Status in Commercially Important NRGs Production – A Review. Multilogic In Science, Vol. VIII, Issue Special (E): 353-357.

Sharma, S. C., J. C. Tewari, N. Prasad, S. K. Pandey and Amit K. Kar. 2016b. Manual on Gum Inducer Technique for Gum Tapping from *Acacia senegal*. ICAR – Indian Institute of Natural Resins and Gums, Ranchi (Jharkhand), India, Bulletin (Technical) No.: 15/2016, 1-27 pp.

Shaw, S. S., S. Patel, Sharad Nema and Ranjeet Kumar Modi. 2010. Network project on harvesting, processing and value addition of natural resins and gums. Annual Progress Report, Directorate of Research Services, Indira Gandhi Krishi Vishwavidyalaya, Raipur, 1-12 pp.

Shiva, M. P., N. P. Singh and F. R. Thakur. 1994. Newly designed improved gum tapping tools. MFP News (Centre of Minor Forest Products, Dehradun, India), Vol. 4 (1): 8-11.

Shiva, M. P., N. P. Singh and F. R. Thakur. 2006. Special tools for safe gum tapping of *Sterculia* and Acacia that do not kill trees. Centre of Minor Forest Products, Dehradun, India. 1-3 pp.

Srivastava, S. and Deb Prasad Ray. 2015. Natural Gum Resources in India and their Commercial Importance. International Journal of Bioresource Science, Vol. 2 (2): 151-155.

USAID (United States Agency for International Development). 2005. Report on the gum *karaya* subsector in Andhra Pradesh, India. International Resources Group (IRG), Washington, DC, 32 pp.

Yogi, R. K., Alok Kumar and A. K. Singh. 2018. Lac, Plant Resins and Gums Statistics 2016: At a Glance. ICAR-Indian Institute of Natural Resins and Gums, Ranchi (Jharkhand), India. Bulletin (Technical) No. 19/2018. 01-80 pp.

■■

Anthropometric Measurements of Female Workers from Madhya Pradesh for Ergonomic Design of Agricultural Machinery

by

Shalini Chaturvedi
Ph. D. Scholar
Dept. of Farm Machinery & Power Engineering,
College of Agricultural Engineering,
JNKVV, Jabalpur, M.P. 485001, INDIA
shalini.stn@gmail.com

Atul Kumar Shrivastava
Professor & Head
Dept. of Farm Machinery & Power Engineering,
College of Agricultural Engineering,
JNKVV, Jabalpur, M.P. 485001, INDIA
atul_jnkvv@yahoo.com

C. R. Chethan
Scientist
ICAR - Directorate of Weed Research,
Jabalpur Ranchi (Jharkhand), INDIA
chethan704@gmail.com

Abstract

A study was conducted to collect the anthropometric data of female agricultural workers of Jabalpur Madhya Pradesh. It represents one of the major districts in the central part of India. Anthropometric data of agricultural female workers are very important for the appropriate and efficient design of farm machinery. Thus, for making the data comprehensive and more useful, a set of 33 body dimensions was collected from 138 agricultural workers, which were found to be applicable in the design of various agricultural equipment. The data was further analyzed and made to illustrate the application of measurements for designing women-friendly equipment. Thus, the (mean ±SD) of weight and stature of selected female workers were found to be (53.71 ±8.07) kg and (1,512 ±56.88) mm, respectively. Anthropometric measurement had a linear relationship with a coefficient of correlation (r = 0.71-0.9) between weight, standing eye height, acromial height, standing elbow height, trochanteric height, sitting height, sitting eye height, knee height (sitting), forward reach, vertical grip reach. The mean stature of female workers of Jabalpur Madhya Pradesh was found to be lower than that of other female populations of different states or parts of the country. Designers of farm machinery need to consider appropriate limit values i.e., 5th and 95th percentile values for the intended user group. For control reach and height of display operation, the designer considers the 5th percentile value and for upper limit such as the design of clearances, seat width, backrest width, etc. the designer should consider the 95th percentile values of an operator.

Keywords: Agricultural Workers, Anthropometry, Body dimension, Ergonomic design, Female

Introduction

Women are the backbone of the agricultural workforce but worldwide their hard work has mostly been unpaid (Tiwari et al., 2014). Theydo the most tedious and back-breaking tasks in agriculture, animal husbandry, and homes. Women are playing a significant role in agricultural development and allied fields including crop production, horticulture, post-harvest, agro/social forestry, fisheries, etc. Nearly 70% of Indian rural women are employed in agriculture and they are responsible for 60-80 % of food production (Tiwari et al., 2011). Thus, women perform extremely tedious, time, and labour-intensive work in the field (Borah, 2015). Postural stress can increase the physiological cost and fatigue during the task and may lead to injuries to the vertebral column in long run (Doomra et al., 2007). Therefore, there is a great need for ergonomic assessment of drudgery of women workers, so that some suitable techniques/technologies can be developed to reduce the drudgery of women workers.

Ergonomics is a scientific study of the man-machine system.Anthropometric data play an important role in designing any implement and it also helps for solving drudgery problems (Shrivastava, 2007). Anthropometry is defined as the "Science of measurement and the application that establishes the physical geometry, mass properties, and strength capabilities of the human body" (Pradu-Lu, 2007). Anthropometry is the study of the human body in both static and dynamic positions. Anthropometric can be defined as the study which deals with body dimensions i.e., body size, shape, strength, and working capacity for design purpose (Shiru and Abubakar, 2012). These definitions also emphasize the analysis of human performance, safety, and satisfaction. Ergonomics is a discipline with a strong tradition in the development and application of methods. In India, the anthropometric survey India has been involved in anthropometric data collection since 1945. The main aim of these surveys has been to collect data on the morphological characteristics of various population groups for anthropological studies (Anon, 1994). The knowledge of body dimensions is essential for designers of equipment and workplaces. The anthropometric measurements are essential for the design of work areas (Ray et al., 1995). Anthropometric data of female agricultural workers are important because of the design of agricultural tools and equipment for women workers (Tewari, 2004). The use of anthropometric data can help in the design of equipment for better efficiency and human comfort.

Aim

The aim of the study was, therefore to collect the anthropometric data of female agricultural workers of one of the major districts i.e., Jabalpur Madhya Pradesh. The major objectives were to collect anthropometric data and make it available to designers, manufacturers for use in farm machinery design.

Literature Review

Anthropometry has three major principles. These principles are mainly being followed in designing. The first principle is "design for extreme individual" which can be either design for the maximum population as commonly the 95th percentile male or design for the minimum population value as commonly referred to as 5th percentile female (Khaspuri et al., 2007). The second principle is "designing for an adjustable range" which put consideration of both 5th female and 95th male to accommodate 90% of the population (Kothiyal and Tettey, 2001). The last principle is "designing for the average" which is mostly being used whenever the use of adjustability is impractical. Attempts are made by many researchers to anthropometric database and ergonomics evaluation of equipment. A concise literature review is shown in **Table 1**. Grandjean (1981) reported that a comfortable range of elbow angle should be 100-110°. He measured the elbow heights (standing) for 5th, 50th and 95th percentile male and female agricultural workers of Meghalaya. Gite and Yadav (1989) collected body dimensions for the design of agricultural equipment. The standard deviation 5th, 50th and 95th percentile values were calculated. The study recommended such extensive surveys in different parts of countries to generate necessary data.

Material and Methods

For the present study, the population for the study comprised of female subjects. Three different villages were selected near JNKVV campus Jabalpur Madhya Pradesh state for data collection. Before starting the collection of the anthropometric data, the sample size has been determined by the formula suggested by (Roebuck et al.,1975) as given below.

$$N = [(K_1S)^2 / d] \quad (1)$$

Where,

N= Sample Size required, no;

S= Estimated standard deviation of the data;

d = The desired accuracy of the measurement, and;

K_1 = A constant.

A total of 138 subjects were taken

Table 1 Review carried out for anthropometric and strength parameter collection

Approach followed	Subject type	Age range (yrs.)	Number of subjects	Anthropometric/ Strength and Parameters measured	Study region	Reference
ADC	Male	15-60	39	52	Bhopal	Gite and Yadav, 1989
ADC	Male	20-50	139	15	West Bengal	Shrivastav, 1994
ADC	Female	18-50	40	30	Gujarat, India	Yadav et al., 2000
ADC	Male	21-48	300	09	Chhattisgarh	Victor et al., 2002
SDC	Male	20-40	944	32	Madhya Pradesh	Agrawal et al., 2010
	Female	25-42	757			
ADC	Male	18-62	878	37	Haryana	Chandra et al., 2011
ADC	Male-Female	20 and above	961	290	23 Locations in India	Chakrabarti, 1997

for the measurement of anthropometric data. The subjects have been chosen from the female farm labour of Jabalpur Madhya Pradesh. The selected female subjects were in the age group of 25 to 45 years. The age group was selected for the study because according to (Reinberg et al., 1975) the peak of muscle strength for both males and women is reached between the age of 25 to 35 years. The anthropometric data were collected keeping in view that they were free from any physical abnormalities and were in sound healthy. The subjects were made acquainted with experimental protocol to ensure their full cooperation (Tiwari et al., 2014). Anthropometric dimensions of the farmworkers in various standing posture were recorded by anthropometer. **Figures 1** and **2** show various anthropometric measurements of farm women in standing and sitting posture such as vertical reach, vertical grip reach, acromial height, eye height, knee height, elbow height, arm reach from the wall, sitting eye height, vertical grip reach sitting, buttock popliteal length, chest breadth, shoulder grip length, elbow-elbow breadth sitting, hip breadth sitting, etc. **Table 2** shows somebody dimension description. All the measurements were conducted using similar techniques. All subjects were asked to stand upright on the base of the anthropometer for the collection of standing dimensions. For sitting dimensions, female subjects were asked to sit erect on a chair without armrests, with knees bent 90°, and feet flat on the surface, facing forward. The data was further analyzed and in addition to the descriptive values 5th, 50th and 95th percentile values were also calculated as shown below. Each group of data was included in statistical analysis.

Analysis of Anthropometric Data

The collected data were analyzed

Fig. 1 Anthropometric dimensions in standing posture

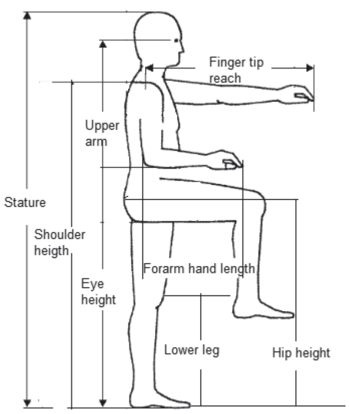


Fig. 2 Anthropometric dimensions in sitting posture

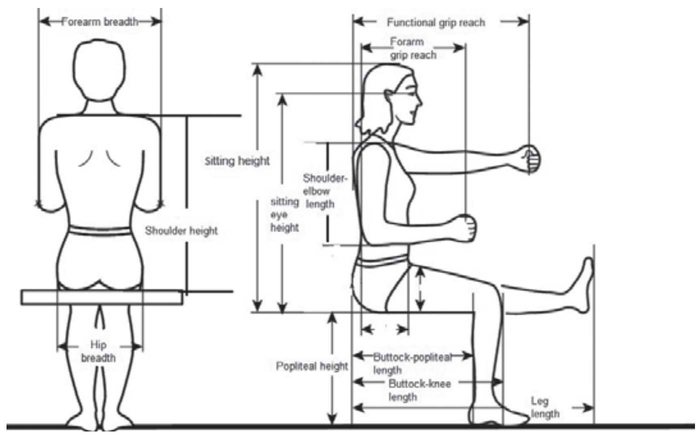


Table 2 Basic Body Dimension

S/No. according to ISO 7250	Basic Body dimension	Description of the body dimensions according to ISO 7250
1	Stature (body height)	Vertical distance from the floor to the highest point of the head (vertex)
2	Sitting height (erect)	Vertical distance from a horizontal sitting surface to the highest point of the head (vertex)
3	Shoulder height, sitting	Vertical distance from a horizontal sitting surface to the acromion
4	Lower leg length (poplitealheight)	Vertical distance from the foot-rest surface to the lower surface of the thighimmediately behind the knee bent at right angle.
5	Hip breadth, sitting	Breadth of the body measured across the widest portion of the hips
6	Elbow height, sitting	Vertical distance from a horizontal sitting surface to the lowest bonypoint of the elbow bentataright angle with forearm horizontal
7	Buttock-popliteal length (seat depth)	Horizontal distance from the hollow of the knee to the rear most point of the buttock
8	Buttock-knee length	Horizontal distance from the foremost point of the knee-cap to the rear most point of the buttock
9	Thigh clearance	Vertical distance from the sitting surface to the highest point on the thigh
10	Eye height, sitting	Vertical distance from a horizontal sitting surface to the outer corner of the eye
11	Shoulder breadth	Distance across the maximum lateral protrusions of the right and left deltoid muscles
12	Body mass (weight)	Total mass (weight of the body) which was measured with the help of weighing scale
13	Knee height	Vertical distance from the floor to the highest point of the superior body of the patella

for each parameter i.e., value of the mean, standard deviation, 5th percentile and 95th percentile was calculated by using the following formulae for a compilation of the data surveyed (Shrivastava et al.,2010).

Mean, $X = (\sum_{i=1}^{n} X) / N$ (2)

Where, X = mean, ∑ = summation, x = Observation, N= total number of observations

Standard Deviation

$\sigma = \sqrt{(\sum X^2)} / N$ (3)

Where, σ = Standard deviation, x = deviation obtained from actual mean, N = Total number of observations

5th percentile, $P_5 = [5(n+1)] / 100$ (4)

95th percentile, $P_{95} = [95(n+1)] / 100$ (5)

Where, n = number of observations

Results and Discussion

Anthropometric Data of Female Agriculture Workers

Various Anthropometric measurements had been taken for the designing of agricultural tools and equipment for the drudgery reduction of farm women. Further, observation was analyzed and maximum, minimum, STDEV, mean, C.V were collected 5th, 95th and 50th percentile population. **Table 3** and **Table 4** present the descriptive statistics of all measured anthropometric measurements of female subjects for both standing and sitting positions. Anthropometric measurements (data) are normally distributed (Helander, 1996). Thus, for all collected data for female workers, the normal distribution curves for stature are hereby

Table 3 Percentile values of different body dimensions of randomly selected female workers in standing positions

Sl. No.	Parameters	Mean	SD	C.V	Min	Max	Percentile values		
							5th	50th	95th
1	Weight, kg	53.71	8.07	0.150	37.1	82.1	41	56	66
2	Stature, mm	1,512	56.88	0.038	1,311	1,668	1,430	1,495	1,652
3	Standing eye height, mm	1,387	56.98	0.041	1,205	1,524	1,310	1,410	1,511
4	Acromial height, mm	1,291	52.46	0.041	1,082	1,363	1,152	1,280	1,342
5	Standing elbow height, mm	930	52.31	0.056	804	1,046	853	965	1,030
6	Inter-elbow span, mm	784.62	43.81	0.056	691.3	864	701	754	855
7	Hip breadth	316.82	62.94	0.199	241	563	244	320	428
8	Elbow functional reach, mm	417.64	33.82	0.081	321	484	342	421	465
9	Crotch height, mm	675.71	47.02	0.070	561	805	600	685	765
10	Trochanteric height, mm	725	42.2	0.058	562	885	649	745	782
11	Arm reach from wall, mm	732	34.1	0.047	573	854	672	750	790
12	Biacromial breadth,mm	283	18.31	0.065	254	320	263	275	305
13	Chest circumference, mm	622	74.61	0.120	610	918	647	721	882
14	Waist circumference, mm	769	53	0.069	625	925	649	691	863
15	Grip diameter, mm	49.6	5.01	0.101	33	61	43	45.6	57
16	Palm length, mm	180.3	18.5	0.103	158	205.2	165.1	178	189.8
17	Forarm- hand length, mm	456.79	28.5	0.062	388.6	522.9	406.3	464	482.6
18	Shoulder elbow length, mm	334.4	32.8	0.098	296.3	376.8	307.7	345	365.2

Table 4 Percentile values of different body dimensions of randomly selected female workers in sitting positions

Sl. No.	Parameters	Mean	SD	C.V	Min	Max	Percentile values		
							5th	50th	95th
1	Sitting height	703.98	43.65	0.0620	501	813	643	691	797
2	Sitting eye height, mm	612.77	37.95	0.0619	532	746	551	658	682
3	Sitting shoulder height, mm	479.2	42.55	0.0887	326	522	378	451	497
4	Sitting elbow height	201	21.72	0.108	163	266	175	194	224
5	Shoulder elbow length	335.5	40.17	0.119	296.3	376.8	307.7	349	365.5
6	Thigh clearance	121.6	13.52	0.111	87.4	156	99.88	128	152
7	Buttock popliteal height	374.5	23.5	0.062	262	413	336	386	402.4
8	Forward reach	639	44.2	0.069	511	724	549	662	718
9	Vertical functional grip reach	948	41.68	0.043	851	1102	878	957	1023
10	Foot length	237.7	21.62	0.090	209.5	289.3	218.6	249	259.62
11	Knee height	469	27.18	0.057	336	521	424	472	511
12	Buttock- popliteal length	466	28.1	0.060	421	544	423	450	524
13	Buttock- knee length	540	32.19	0.059	424	611	456	562	580
14	Bideltoid	388	26.6	0.068	314	467	332	391	426

presented in **Fig. 3** and same as the normal distribution curve for weight, sitting height, buttock popliteal length, and knee height are presented in **Fig. 5** and **Fig. 3** shows the Pareto chart of a cumulative frequency distribution of the stature of a subject.

The mean stature of farm women in Madhya Pradesh was found 1,512 mm whereas, 5th, 95th and 50th percentile were 1,430, 1,495, 1,652 mm, respectively. The mean weight of farm women was found 53.71 kg, however, 5th, 95th and 50th percentile of weight were 41, 56, and 66 kg, respectively. weight of farm women ranged between 40-70 kg. It shows the fact that the weight of tools or equipment for women should be friendly and comfortable to use. Heavyweight tools or equipment may be heavy for them.

The mean eye height of women was observed 1,387 mm. Mean standing elbow height and elbow functional reach were 930 and 417.64 mm respectively whereas the 5th percentile of the above measurements was 853 and 342 mm respectively. To have a comfortable operation by 90% of the population, the handle holding height should be designed based on the 5th percentile value. This range value helps in deciding the possibility ofan adjustable design of the tool and equipment. The most favorable working height for handwork while standing is 55-100 mm, below elbow level. The mean grip diameter and palm length were observed at 49.6 and 180.3 mm. Thus, these data help in designing the handle of the equipment. The maximum handle height should be 940 mm for the equipment to be operated by a female worker.

Various anthropometric measurements of farm women were taken in a sitting position. An observation regarding sitting height, sitting eye height, sitting shoulder height and knee height can be used in the designing of the seat of the machine. The 5th, 95th and 50th percentile values of sitting were 643, 691 and 797 mm. values of sitting eye height were 551, 658, and 682 mm, respectively. The values for sitting shoulder height were 378, 451, and 497 mm. The knee height for 5th, 95th and 50th were 424, 472, and 511 mm respectively. These data help in determining the leg reach envelope of the subject.

Relationship Among Anthropometric Dimension

The coefficient of correlation and constants of the linear equations for different parameters of female agricultural workers are presented in **Table 5**. It was observed that most of the measurements such as standing eye height, sitting height, knee height, and vertical grip reach had a fairly good linear correlation with stature. the correlation coefficient varied from 0.92 to 0.99. among other parameters such as weight, acromial height, standing elbow height, standing elbow height and forward reach had correlation ranged from 0.82 to 0.88 with stature. Similarly,trochanteric height had an average correlation of 0.782 with stature. the correlation between sitting eye height and sitting height was found to be 0.713.

Fig. 3 and **Fig. 5** describe the nor-

Table 5 Relationship among anthropometric data of female agriculture workers

Sl. No.	Anthropometric body dimension	Independent parameter	Constant	Coefficient	Correlation coefficient (r)
1	weight	stature	-103.6	0.103	0.882
2	Standing eye height	stature	102.8	0.857	0.947
3	Acromial height	stature	82.21	0.770	0.824
4	Standing elbow height	stature	-159.0	0.726	0.857
5	Trochanteric height	stature	-86.22	0.531	0.782
6	Sitting height	stature	-342.7	0.690	0.999
7	Sitting eye height	Sitting height	99.26	0.747	0.713
8	Knee height	stature	-88.44	0.365	0.915
9	Forward reach	stature	-404.3	0.686	0.828
10	vertical grip reach	stature	21.80	0.610	0.920

Fig. 3 Normal distribution curve for stature of female anthropometric data

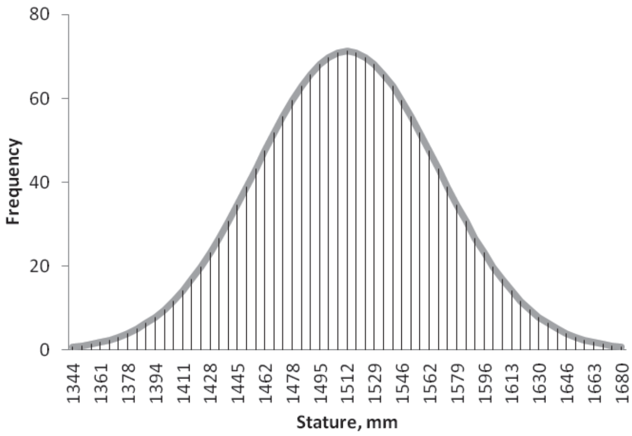
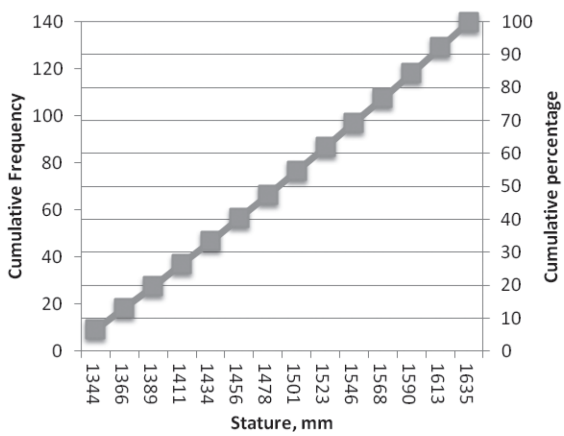


Fig. 4 Pareto chart of cumulative frequency distribution of stature of subject



mal distribution of stature, weight, sitting height, buttock popliteal length, and knee height. The normal distribution is the most important probability distribution in statistics because it fits many natural phenomena (Shrivastava, 1994). Thus, the curve shows theoretically exactly symmetrical. The mean value of stature is 1,512 mm well shown in a curve assymmetrical and bell-shaped. **Fig. 4** shows the Pareto chart of cumulative frequency for the stature of female agriculture workers. Representing cumulative frequency data on the graph is the most efficient way to understand the stature data of female agriculture workers and derive results. The Pareto chart also represents the cumulative percentage in the preceding size of the workers. **Fig. 4** defines that the left vertical axis is the frequency of occurrence and the right vertical axis is the cumulative percentage of the total occurrence. The purpose of the Pareto chart is to highlight the important thing among a set of factors. The frequency of stature of subjects was increasing order from 1,334 to 1,635mm respectively.

Variation in Anthropometric Body Dimension Across States of India and Other Countries

Comparison of ten body dimensions with similar anthropometric studies conducted by Arunachal Pradesh, Mizoram, Meghalaya, Tamil Nadu, Madhya Pradesh, Gujarat and West Bengal, data presented in **Table 6**. It was observed that the mean weight of female workers of Madhya Pradesh was highest among all the population means. The mean stature of female workers of West Bengal was higher than that of Madhya Pradesh. Thus, the mean stature of Madhya Pradesh was lower than that of all other populations of the country. The knee height of Madhya Pradesh workers was 469 mm and the highest knee height was observed in Mizoram workers. The grip diameter of outside and inside of all population hasa nearly similar trend.

The mean values of anthropometric data were also compared with anthropometric data of female workers of 5 countries and reported in **Table 7**. The mean weight of Sweden's female agricultural workers was highest among all female workers of other countries. Thus,the mean stature of Sweden's female workers was also highest than that of Indian workers and other country female workers. The differences found in the anthropometric dimensions of the different populations of countries emphasize the usefulness of this study in the context of the design of agricultural hand tools and implement. This implies that the device and implements designed abroad should be suitably modified before introducing these to the Indian farmworkers.

Fig. 5 Normal distribution curve for female anthropometric data

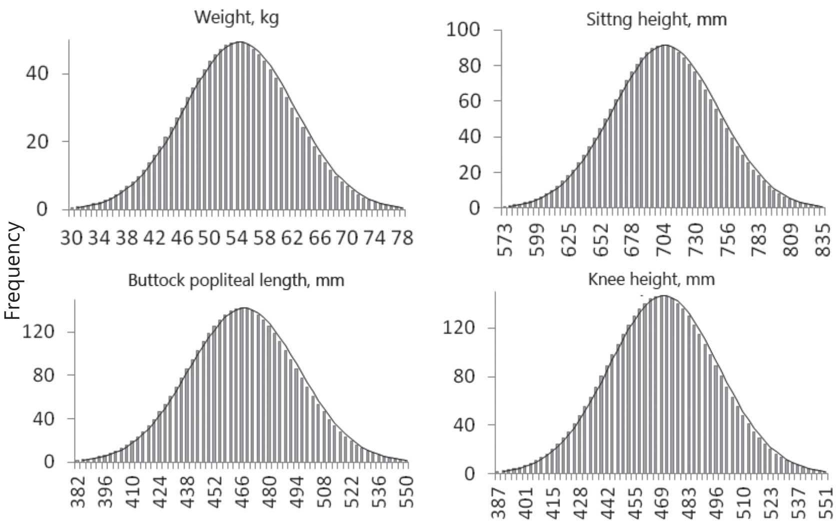


Table 6 Comparison of mean values of anthropometric data of female agricultural workers of Madhya Pradesh with other states of India (mm)

Sl. No.	Body dimension	Madhya Pradesh (Present study)	Mizoram[a]	Meghalaya[e]	Tamil Nadu[b]	Arunachal Pradesh[a]	Gujarat[c]	West Bengal[d]
1	Weight, kg	53.71	46.5	47.0	47.3	48.5	46.4	42.5
2	Stature	1,512	1,531	1,308	1,508	1,525	1,516	1,499
3	Knee height	469	595	428	442	409	461	413
4	Hip breadth	316.82	305	251	264	293	296	307
5	Acromial height	1,291	1,292	1,242	1,258	1,264	1,264	1,243
6	Bi-acromial breadth	283	339	287	282	334	291	288
7	Chest circumference	622	795	837	779	861	791	533
8	Fore arm hand length	456.79	399	395	419	407	429	406
9	Grip diameter (inside)	49.6	44	36	46	44	40	42
10	Grip diameter (outside)	86	71	63	65	74	82	74

[a]Prasad, et al. (1999), [b]Anon (2002), [c]Anon (2005), [d]Tewari and Ailavadi (2002), [e]Agrawal, et al. (2005)

Some Design Challenges

In designing any machine some design challenges need to be addressed to achieve anthropometric measurements. Some design challenges are as follow:

1. For designing any machine make the strategy so that all percentile people can be able to use the designed product.
2. A designer should be designed in such a way that there is mostly only one size that fits all.
3. The design product is fit for body size and shape.
4. Design for comfortable. This means that a person has average body height, still might be having a popliteal height or other body partsthat are not of average size.

Conclusions

The study has been undertaken to provide anthropometric data of 33 body parts of women farmworkers, which might be used with aid of designers for the ergonomic design of the agricultural machine.In the comparison of anthropometric data with other states, it was found that the mean weight of femaleworkers of Madhya Pradesh was higher among other states of female workers. Similarly, the anthropometric data of Indian female workers are compared with other country and it was found that the mean weight of Sweden country female workers are highest among all female workers of other countriesThe comfortable range of holding manually operated Millet thresher machine equipment should be 0.8 of shoulder height. As per equipment operated by female workers, it should be 0.8 of the 5th percentile acromial height. A good working posture can be sustained with a minimum of static muscular effort and it will possible to the workers to perform the given task more effectively and with the least muscular discomfort. Therefore, the wheel hoe should be such that the female operator does not have to exert more than 26 N push or 31 N pull.For the optimum area of hand control, the elbow pivot having 95th percentile value of wall to acromion distance and the controls are located 5th percentile value of the operator. Thus, the compilation of anthropometric data is much needed and worthwhile to design tools and equipment as well as assess them ergonomically. Since women's participation in various agricultural operations is steadily growing. The data can be used to design area-specific tools and equipment and can reduce occupational health problems and injuries. Designers of farm machinery need to consider appropriate limit values i.e., 5th and 95th percentile values for the intended user group. They also consider some design challenges before designing any machine which will helpful for the health status of agricultural female workers. For control reach and height of display operation, the designer considersthe 5th percentile value and for the upper limit such as the design of clearances, seat width, backrest width, etc. the designer should consider the 95th percentile values of the operator.

Acknowledgment

The Author is thankful to CSIR (Council of Scientific & Industrial Research) New Delhi, for providing valuable monetary support for the research work.

Table 7 Comparison of mean values of anthropometric data of female agricultural workers of India with other countries (mm)

Sl. No.	Body dimension	Present Study	USA[a]	UK[b]	Sweden[c]	Indonesia[d]	Japan[e]
1	Weight, kg	53.71	60.2	59.4	61.3	55.8	57.7
2	Stature	1,512	1,626	1,610	1,674	1,524	1,569
3	Knee height	469	505	500	521	490	505
4	Hip breadth	316.82	376	370	416	299	333
5	Bi-acromial breadth	283	NA	355	350	NA	348
6	Sitting height	703.98	861	850	892	774	850
7	Sitting shoulder height	479.2	564	555	577	506	514
8	Foot length	237.7	239	NA	243	223	NA
9	Buttock-popliteal length	466	490	480	477	451	437
10	Buttock- knee length	540	574	570	596	527	531

[a]MacLeod (2000), [b]Barroso, et al. (2005), [c]Hanson, et al. (2009), [d]Syuaib (2015), [e]Lin, et al.(2009)

REFERENCE

Agrawal, K. N., R. K. Singh and K. K. Satapathy. 2005. Development/modifications of Tools and Equipment based on Ergonomical Consideration for Hill Agriculture in Meghalaya.FinalReportof AdhocResearchProject. ICAR Research Complex for NEH Region, Umiam, Meghalaya, 80-85

Agrawal, K. N., P. S. Tiwari, L. P. Gite and V. Bhushanababu. 2010. Isometric Push/Pull Strength of Agricultural Workers of Central India. Agricultural Engineering International the CIGR journal. Manuscript 1342 Vol. XII.

Anon. 1994. All Indian Anthropometric Survey North Zone (Basic Anthropometric Data). Anthropometric Survey of India Kolkata, 11 (Part 1).

Anon. 2002. Annual Report AICRP on Human Engineering And Safety Analysis. Coimbatore Centre, Tamil Nadu Agricultural University, Coimbatore, 273-278.

Anon. 2005. Yearly Report of Adhoc Project on Anthropometric Survey and Ergonomics Studies on Agricultural Workers of Gujarat for Efficient and Safe Design of Agricultural Equipments. Gujarat Agricultural University Junagarh. 3-25

Barroso, M. P., P. M. Arezes, L. G. Costa and A. S. Miguel. 2005. Anthropometric study of Portuguese workers. International Journal of In-

dustrial Ergonomics 35(5): 401-410.
Chakrabarti, D. 1997. Indian Anthropometric Dimensions for Ergonomic Design Practice. India: National Institute of Design, ISBN 81-86199-15-20.
Chandra, A., P. Chandna and S. Deswal. 2011. Analysis of Hand Anthropometric Dimensions of Male Industrial Workers of Haryana State. International Journal of Engineering (IJE). 5(3): 242-256.
Dewangan, K. N., C. Owaryand and R. K. Datta. 2008. Anthropometric data of female farm workers from north eastern India and design of hand tools of the hilly region. International Journal of Industrial Ergonomics,38(1): 90-100.
Doomra, Z., K. Singh, M. Mehta and M. E. Dilbagi. 2007. Developments in Agricultural and Industrial Ergonomics: Women at work (vol II). Cattle Milking – A strenuous Activity Performed by Rural Women. Allied Publishers Pvt. Ltd., pp. 3-7.
Gite, L. P. and B. G. Yadav. 1989. Anthropometric survey for agricultural machinery design. Applied Ergonomics. 20(3): 191-196.
Grandjean, E. 1981. Fitting the task to the man. London: Taylor and-Francis.
Hanson, L., L. Sperling, G. Gard, S. Ipsen and C. O. Vergara.2009 Swedish anthropometrics for product and workplace design. Applied Ergonomics 40(4): 797-806.
Khaspuri, G. C., S. K. Sau and P. C. Dhara. 2007. Anthropometric consideration for designing classroom furniture in rural schools, Journal of Human Ecology. 22(3): 235-244.
Kothiyal, K. and S. Tettey. 2001. Anthropometry for design for the elderly, International Journal of Occupuational Safety Ergonomics.: 7(1): 15-34.
Lin, Y. C., M. J. Wang and E. M. Wang. 2004 The comparisons of anthropometric characteristics among four people in East Asia. Applied Ergonomics 35(2): 173-178.
MacLeod, D. 2000. The rules of work, A Practical Engineering Guide to Ergonomics. Taylor and Francis, Florida.
Helander, M. 1996. A Guide to the Ergonomics of Manufacturing, First Ed..East-West Press and Taylor& Francis
Pradu-Lu, J. L. D. 2007 Anthropometric measurement of Filipino manufacturing workers. International Journal of Industrial Ergonomics 37: 497-503
Prasad, N., K. N. Dewangan and A. N. Pandey. 1999.Anthropometry of North Eastern Indian Agricultural Workers. Agricultural Mechanization Of Asia, Africa And Latin America, 30(4): 76-80.
Ray, G. G., S. Ghosh and V. Atreya. 1995. An anthropometric survey of Indian schoolchildren aged 3-5 years. Applied Ergonomics 26: 67-72.
Shiru, J. J. and S. Abubakar. 2012. Anthropometry in Engineering Design (A Case Study of Cassava Grating Machines Installed In Doko and Kutigi Metropolis of Lavun Local Government Areas of Niger State. Niger. Acad. Forum 22(1): 132-139
Shrivastava, A. 1994. Some investigation on an animal drawn rotary puddler from mechanical and ergonomical point ofin view, Unpublished Ph. D submitted in dept. of Agricultural and food Engineering, Indian Institute of Technology, Kharagpur, (W.B.), India.
Shrivastava, A. 2007. Anthropometric Survey of Northern-Eastern Indian Farm Workers. Proceedings in Agriculture Ergonomics Development Conference IEA Press, Kuala Lumpur.
Shrivastava, A., C. R. Mehta and M. M. Pandey. 2010. Accessibility Index of Indian Tractors – A Case Study Agricultural Mechanization in Asia, Africa & Latin America 41(3): 17-22.
Swapnali, B. 2015. Ergonomic assessment ofdrudgery of women worker involved in cashew nut processing factory in Meghalaya, India .6th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences.
Syuaib, M. F. 2015. Anthropometric study of farm workers on Java Island, Indonesia, and its implications for the design of farm tools and equipment. Applied Ergonomics 51: 222-235.
Tewari, V. K. and R. Ailavadi. 2002. Ergonomics Database for Engineering Design of Agricultural Machines. Adhoc Research Final Report, Agricultural and Food Engineering Department, IIT Kharagpur.
Tiwari, P. S., M. M. Pandey, L. P. Gite and A. K. Shrivastava. 2011. Pedal power for occupational activities: Effect of power output and pedalling rate on physiological responses. International Journal of Industrial Ergonomics 41(3): 261-267.
Tiwari, P. S., M. M. Pandey, L. P. Gite and A. K. Shrivastava. 2014. An ergonomic intervention in operation of a rotary maize sheller. Indian Journal of Agricultural Sciences 84(7): 791-795.
Tiwari, P. S., M.M. Pandey, L.P. Gite, and A.K. Shrivastava.2014. Development of a dynapod for occupational activities in agriculture. Journal of Agricultural Engineering Vol. 51(4).
Tewari, V. K. 2004. Ergonomic database for engineering design of agricultural machines. Final Report, Agricultural and Food Engineering Department, IIT Kharagpur.
Victor, V. M., S. Nath and A. Verma. 2002. Anthropometric survey of Indian farm workers to approach ergonomics in agricultural machinery design. Applied Ergonomics, 33(6): 579-581.
Yadav, R., L. P. Gite, N. Kaur and J. Randhawa. 2000. An anthropometry of Indian female agricultural workers. Agricultural Mechanization in Asia, Africa and Latin America. 31(3): 56-60. ■■

Effect of Tuber Shape, Picking Cup Size and Peripheral Speed of Metering Unit on Tuber Metering Efficiency of Belt Type Automatic Potato Planter

by
C. R. Chethan
ICAR - Directorate of Weed Research,
Jabalpur, INDIA

A. K. Shrivastava*
Jawaharlal Nehru,
Krishi Vishwa Vidyalaya,
Jabalpur, INDIA
*Corresponding Author: atul_jnkvv@gmail.com

B. Nare
ICAR - Central Potato Research Station,
Jalandhar, INDIA

S. P. Kumar
ICAR - Central Institute of Agricultural Engineering,
Bhopal, INDIA

P. K. Singh
ICAR - Directorate of Weed Research,
Jabalpur, INDIA

S. A. Venu
ICAR - Indian Institute of Horticultural Research,
Bengaluru, INDIA

K. Manjunath
ICAR - Directorate of Cashew Research,
Puttur, INDIA

S. Chaturvedi
Jawaharlal Nehru,
Krishi Vishwa Vidyalaya,
Jabalpur, INDIA

Abstract

Potato (*Solanum tuberosum* L.) is one of the most important food crops in world. Uniform spacing of potato seed tubers in a furrow improves tuber quality, increases tuber yield and ease field difficulties while harvesting and post-harvest processing of tubers. Uniform spacing of tubers by cup-belt type automatic potato planter is influenced by size of picking cups, peripheral speed of metering unit and tuber physical properties. The mechanical deficiencies planter metering mechanism increases tuber doubles and skips and also yields higher CV% in tuber spacing. Ultimately the tuber yield gets affected. Thus, effect of tuber shape (S_1 & S_2), cup size (C_1, C_2 & C_3) and peripheral speed of metering unit (P_1, P_2 & P_3) was studied to improve the planter metering efficiencies. The tuber doubles significantly affected by all the parameters and at least doubles of 3.44%, 3.56% & 4.56% was obtained respectively in C_1, S_2 and P_3 treatments. The tuber skips was significantly affected only by cup size and peripheral speed of metering unit. The least skips% of 2.44% and 2.56% was obtained respectively in C_3 and P_1 treatments. The CV% was significantly varied by all the parameters and least CV% of 23.16%, 23.22% and 24.98% was obtained respectively in P_1, C_2 and S_2 treatments. The more irregular shaped tubers with cup size C_2 and operating at peripheral speed of 0.21 to 0.35 m/s gives more uniform spacing of tubers within furrow.

Keywords: CV%, Cup size, Shape factor, Peripheral speed, Tuber spacing.

Introduction

Potato (*Solanum tuberosum* L.) family (Solanaceae) is one of the most important food crop and abundantly grown edible crop in the world. Potato is native to the South America, but cultivated all over the world and stands fourth position in cultivation after rice, wheat and maize (Khurana, 2002). Likewise, in India also, the potato ranks fourth most important food crop after rice, wheat and maize and accounts 1.23 percent of gross agricultural production. India is the second largest producer of potato after China with a production of 51.3 million tonnes from 2.14 million hectare area, having an average productivity of 23.96 Mt/ha during 2017-18. During 2016, India produced a 44 million tonnes of potato out of 377 million tonnes of world production, which holds a share of about 11.6% of global production (Anon, 2018). There was tremendous increase in potato productivity was observed in India, which was about 47.5% increase within a span of two decades i.e. productivity was increased from 16.0 Mt/ha during 1991-92 to 23.96 Mt/ha during 2017-18. However, the countries like USA and European countries have higher crop productivity, which ranges from 49 to 42 Mt/ha.

Seed is a costly and critical input in potato production because, potato is asexually propagated. The cost of potato seed alone accounts about 36-38% percent of the total cost of cultivation (Peer et al., 2013; Raghuvanshi et al., 2018; Chethan et al., 2019; Chethan et al., 2021) in potato production. The situation of increase in seed cost further increases and becomes prime most factors in the cultivars, which produces the large size tubers. There is an acute shortage of small size (10-20 g) healthy seed tubers during planting season of the potatoes. One of the solutions to overcome this problem is using an efficient metering unit and planter to minimize seed wastages (Boydas, 2015). The potatoes are planted by using tractor and/or power tiller operated semi-automatic and automatic planters using either cup-belt type, ring magazine type or picker wheel type metering mechanism. The automatic planter requires less manual labors and efficiently places the seed potato to a desired depth and spacing within furrow. However, cup-belt metering unit is popular and proves to be efficient among other metering seed metering mechanisms. Moreover, the metering mechanism is a crucial part in any planter as it influences seed placing accuracy within furrow. The uniformly spaced seed tubers give higher yield, improves tuber quality and also ease the field difficulties while harvesting and post-harvest processing of tubers (McPhee et al., 1996; Pavek and Thornton, 2003; Buitenwerf et al., 2006; Bussan et al., 2007; Güllüoglu and Arioglu, 2009; Boydas and Uygan, 2012; Boydas, 2015).

Fig. 1 Potato planter selected for study

It has been reported that, increase or decrease in plant population by 10% leads reduction tuber yield by 2 to 12% (Rupp and Thornton, 1992). The increase in values of tubers skips and/or doubles decreases the economic return compared to the uniformly spaced tubers (Klassen, 1974; Klassen, 1975; Rupp and Thornton, 1992). Some researchers found that, more than 88% of plant skips are because of seed absent and most of the skips caused due to mechanical deficiencies of potato planter (James et al., 1975; Misener, 1979). However, the mechanical deficiencies are may be due to using of improper sized cups, peripheral speed of planter metering mechanism, and tuber physical properties (Khairy, 1997; Altuntas, 2005; Al-Gaadi and Marey, 2011). The cup-belt type metering mechanism is mostly used for large sized potato seeds and design of cup is mainly dependent on size and shape of potato tubers. The efficiency of agricultural equipments is influenced by physical properties of the seeds (Kutzbach, 1989). Moreover they should consume less energy for field operation (Chethan et al., 2018). Therefore, the physical properties of the tubers must be considered while designing a machine. The shape of potato tuber is one of the important characteristic which influences handling and transporting. Combination of shape features with size of tubers can be used for distinguish purpose (Tao et al., 1995; Zo¨dler, 1969; Koning de et al., 1994). The different potato varieties show different shape characteristics. In totality all these parameters influences the performance of seed metering mechanism. To obtain uniform picking and spacing of tubers, uniform shape of potato tuber with proper cup size and metering unit operating speed should be used. Therefore it is necessitated to evaluate the planter performance for seed uniformity (Zoraki and Acar, 2000; Seyedbagheri, 2006; Boydas and Uygan, 2012; Boydas, 2015). This study was under taken to increase the tuber metering efficiency of cup-belt type automatic planter to obtain uniform spacing of tubers.

Materials and Methods

The experiment was conducted under laboratory condition according to the procedure detailed in IS: 9856 – 1981, 1982; IS: 11893 – 1986, 1987; Hardik, 2014; Boydas, 2015. A novel automatic belt type potato planter developed for cut tuber planting at ICAR-Directorate of Weed Research, Jabalpur, India was selected for the study (**Fig. 1**).

2.1 Tuber Shape Factor

A potato crop variety Kufri Chandramukhi was selected for the study and it had oval to long shaped tubers (Anon., 2020). The oval (S_1) and long (S_2) shaped potato tubers results higher uniformity index % than round shaped tubers (Boydas and Uygan, 2012; Boydas, 2017), thus, these shape factors were selected for the study. Total 50 number of tubers were selected under each shape category, their physical dimensions were measured by using a digital vernier caliper (Mitutoyo 500 196 30, ±0.001 inch accuracy) to calculate the shape factor. The following formulae is used to

$$S = 100(a^2 / bt) \quad (1)$$

Where, S is the shape factor; a is the length in mm; b is the width of potato tuber in mm; t is the height or thickness of potato tuber in mm with t < b < a (Mohsenin, 1986).

2.2 Tuber Picking Cup Size and Peripheral Speed of Metering Unit

A half spherical shaped tuber picking cups were developed and were tested under laboratory condition to check percent coefficient of variation (CV %) of planting accuracy. A round shaped edge was maintained to avoid the mechanical damage to the tubers caused by cup sharp edge. All the cups were fabricated by cast iron. Three different sizes of cup C_1, C_2 and C_3 were used in the study. The dimensions of the selected cups are given in **Fig. 2** and **Table 1**.

The potato planter consists of two number of cup-belt systems to plant the tubers in two rows. One number of cup-belt systems was used individually for each row. The potato metering unit consists of cup-belt system, rotating pulleys, chain sprocket system and ground wheel. The tuber picking cups were mounted on a rubber belt having a thickness of 10 mm and width of 120 mm.

Cups were placed at a distance of 100 mm in zig-zag manner. A proper speed ratio was maintained between the metering unit and the ground wheel to achieve tuber to tuber spacing of 200 mm in furrows. A100 mm cast iron pulleys were used to drive the belts. A centre to centre distance of 840 mm was used between the pulleys. These pulleys were powered by ground wheel through chain-sprocket system.

The forward speed of planter influences tuber planting accuracy and spacing uniformity within a furrow. The angular speed of metering unit is directly proportional to the forward speed of planter. Therefore it is necessitated to select an accurate angular speed to obtain uniform metering of tubers. Thus, three angular speeds viz. 0.21 (P_1), 0.35 (P_2) and 0.49 (P_3) m/s which are proportional to planter forward speed of 1.5, 2.5 and 3.5 km/h respectively was selected for the study.

2.3 Evaluation of the System for Tuber Metering Efficiency

The selected shape factor (S_1 and S_2), cup size (C_1, C_2 and C_3) and peripheral speed of metering unit (P_1, P_2 and P_3) was evaluated under laboratory conditions. A time interval (t) between successive tubers passes for 100 numbers of times was measured. An Infrared sensor based tuber detection system was used to measure the time interval between two successive tubers. The time interval between two successive tubers should be sufficient enough to allow the tuber to be placed exactly at 200 mm distance and it is calculated on the basis of peripheral speed of metering unit. The respective time interval for selected peripheral speeds of 0.21, 0.35 and 0.49 m/s is 0.48, 0.29 and 0.2 seconds. A time threshold values were used to calculate the doubles and skips. The used threshold values are given below (Boydas, 2015):

i. If the time interval between two successive tubers (t_d) is $\leq t \times 0.7$, then it is said to be tuber doubles.
ii. If the time interval between two successive tubers (t_s) is $\leq t \times 1.5$, then it is said to be tuber skips

The following parameters used to evaluate for tuber picking efficiency of belt type automatic potato planter

a. Doubles %

If the spacing between two adjacent tubers is equal or less than one-third of the desired spacing, then the tubers is said to be doubles. The threshold time value td is used to decide the tuber double. The tubers double percent is the ratio of number of double tubers (D_t) to the total tubers (D_T) within a unit length.

$$\text{Doubles } \% = (D_t / D_T) \times 100 \quad (3)$$

b. Skips %

If the spacing between two adjacent tubers is equal or more than twice the desired spacing then the tubers is said to be skip. The threshold time value ts is used to decide the tuber skips. The tubers skips percent is the ratio of number of skipped tubers (S_t) to the total tubers (D_T) within a unit length.

$$\text{Skips } \% = (S_t / D_T) \times 100 \quad (4)$$

c. Coefficient of Variation (CV) of seed spacing

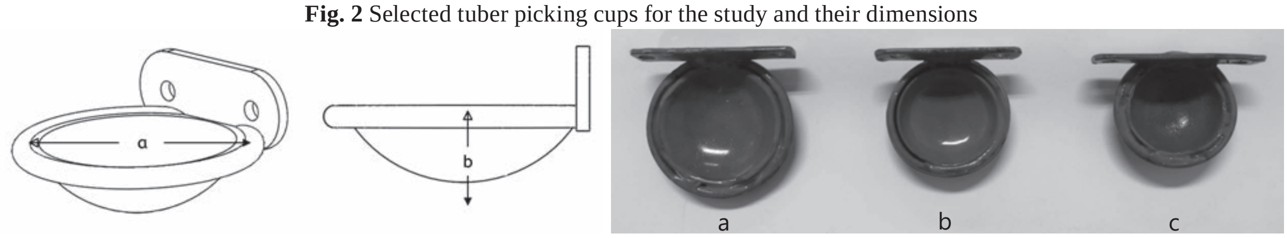
The spacing uniformity of planted tubers within a row is measured by calculating the CV% and it is calculated without missed and accumulated tubers. Obtaining least values of CV% indicates, more uniform is

Table 1 Dimensions of the selected cups

S. No.	Cups	a, mm	b, mm
1	C_1 (Small)	40	15
2	C_2 (Medium)	54	21
3	C_3 (Large)	65	25

Source: Boydas and Uygan, 2012; Boydas, 2015

Fig. 2 Selected tuber picking cups for the study and their dimensions



a. Dimensions of the cup b. Selected tuber picking cups

Table 2 The physical dimensions of the selected tubers

Physical dimensions	Oval shaped tuber	Long shaped tuber
Length, mm	57.48 ±5.12	79.66 ±7.65
Width, mm	45.63 ±5.03	53.09 ±6.95
Thickness, mm	38.07 ±4.06	42.01 ±5.61
Shape factor	192.04 ±20.93	287.98 ±25.5

Table 3 Effect of shape factor, cup size and peripheral speed on CV%, doubles and skips

Treatment	CV, %	Doubles, %	Skips, %
Shape factor (fa)			
1: Oval	26.67^{A}	6.56^{A}	3.37
2: Long	24.98^{B}	3.56^{B}	3.70
LSD (p=0.05)	0.93	0.44	NS
Cup size (fb)			
1: Small	27.48^{A}	3.44^{C}	5.11^{A}
2: Medium	23.22^{B}	4.67^{B}	3.06^{B}
3: Large	26.78^{A}	7.06^{A}	2.44^{C}
LSD (p=0.05)	1.14	0.54	0.50
Peripheral speed of metering unit (fc)			
1: 0.21 m/s	23.16^{C}	5.50^{A}	2.56^{C}
2: 0.35 m/s	24.78^{B}	5.11^{A}	3.28^{B}
3: 0.49 m/s	29.53^{A}	4.56^{B}	4.78^{A}
LSD (p=0.05)	1.14	0.54	0.50

the tubers spaced within row. The following equations are used to compute the CV %:

$$CV\ \% = (\sqrt{V_X} / \bar{X}) \times 100 \quad (2)$$

Where, $\bar{X}$ is mean value of tuber spacing, mm; V_X is variance of seed spacing, mm.

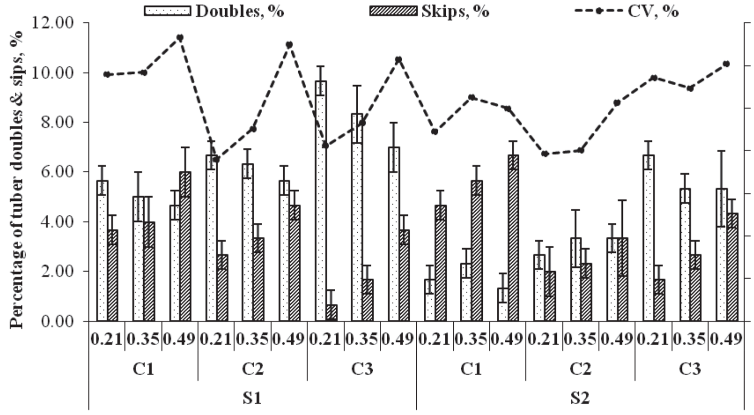
2.3 Statistical Analysis

Three different size half spherical shaped tuber picking cups were evaluated at two shape factors and at three different peripheral speed of metering mechanism. These treatments were replicated thrice and was analyzed with ANOVA in SAS software (Version 9.4M7 / August 18, 2020, SAS Institute, US) for different dependent parameters. The analysis inferences were drawn at 5% level of significance.

Result and Discussions

The physical dimension of the tubers under both oval and long shaped tubers was measured and selected parameters were evaluated under laboratory conditions. A shape factor of 192.04 ±20.93 was obtained under oval and 287.98 ±25.5 was obtained under long shaped tubers (**Table 2**).

Fig. 3 Effect of different treatments on tuber doubles, skips and CV%



3.1 Effect on Tuber Doubles

The tuber doubles significantly affected by tuber shape factor ($F = 192.97$, $P < 0.05$), cup size ($F = 96.44$, $P < 0.05$), peripheral speed of metering unit ($F = 6.44$, $P < 0.05$), whereas their interaction does not have any effect (**Table 4** and **Fig. 4**). Under tuber shape factor, oval shaped tubers yielded highest tuber doubles (6.56%) followed by long shaped tubers. Under cup size, the highest tuber doubles of 7.06% was observed in large cup (diameter of 65 mm and depth of 25 mm) followed by 4.67 and 3.44% respectively in medium and small cups. Under peripheral speed, the highest tuber doubles of 5.5% observed in 0.21 m/s followed by 0.35 m/s, however results were statistically at par. The peripheral speed 0.49 m/s resulted lowest tuber doubles of 4.56% (**Table 3** and **Fig. 3**). It is because; at higher peripheral speed picking cups will get very less time to pick the tubers. Also, at higher speed operation, the moment of inertia and tuber vibration will also be higher. This causes excess tubers presented on cup to get vibrate and fall back in to the duct. Similarly, the larger cup had more space which gives more room to accommodate more number of tubers to sit and vice-versa. The more irregularity of the seed tuber shape gives very less tuber doubles (Boydas and Uygan, 2012; Boydas, 2017).

3.2 Effect on Tuber Skips

The tuber skips significantly affected by cup size ($F = 63.23$, $P < 0.05$), peripheral speed of metering unit ($F = 41.63$, $P < 0.05$) and interaction effect of shape factor and cup size ($F = 10.9$, $P < 0.05$), but not affected by interaction effect with peripheral speed (**Table 5** and **Fig. 5**). The irregularity of tuber shape

(shape factor) does not have any effect on tuber skips. Under cup size, a highest tuber skips of 5.11% was obtained in small size cups followed by 3.06% in medium and 2.44% in large size cups. Under peripheral speed, highest tuber skip of 4.78% was observed in 0.49 m/s followed by 3.28 and 2.56% respectively in 0.35 and 0.21 m/s. Even though, the shape factor does not affect tuber skips, but it had considerable skip percent of 3.37 to 3.7% (**Table 3** and **Fig. 3**). As detailed in the case of tuber doubles, lesser time and less space available to pick tubers at higher speed and in small cups, the tuber skip was increased. A least percent of tuber skip was observed at 0.21 m/s and in larger cups because of more time and space available for tuber pick (Boydas and Uygan, 2012; Boydas, 2017).

3.3 Effect on Coefficient of Variation of Tuber Spacing

The percent coefficient of variation (CV%) significantly affected by tuber shape factor (F = 13.62, P < 0.05), cup size (F = 93.82, P < 0.05), peripheral speed of metering unit (F = 69.99, P < 0.05) and with their interaction effects (**Table 6** and **Fig. 6**). Under peripheral speed of metering unit, a highest CV of 29.53% was obtained at 0.49 m/s followed by 24.78 and 23.16% respectively at 0.35 and 0.21 m/s. Under cup size, a highest CV of 27.84% was observed in small size cup followed by 26.78% in large and lowest of 23.22% in medium size cup. Under shape factor, the highest CV of 26.67% was observed in oval shaped tubers and lowest of 24.98% in long shaped tubers (**Table 3** and **Fig. 3**).

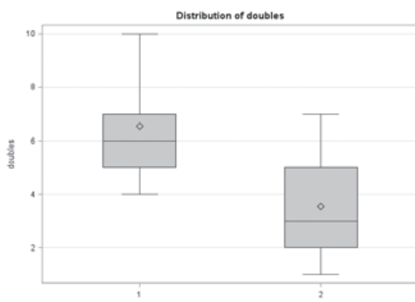
In general, when tuber spacing uniformity within a furrow is consider, CV% plays a very important role and lowest CV will give more uniformed spacing. It was observed that, the CV% increases with increase in peripheral speed and decrease in shape factor (long to oval shaped tubers). But under cup size treatment, the condition was little different. The Lower CV%

Table 4 ANOVA table to determine effect of different treatments on tuber doubles

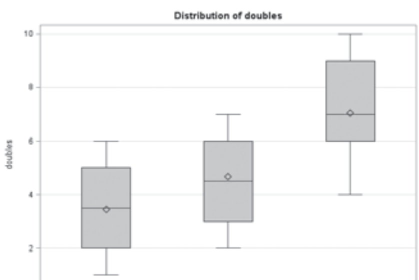
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
fa	1	121.50	121.50	192.97	< .0001
fb	2	121.44	60.72	96.44	< .0001
fa × fb	2	1.44	0.72	1.15	0.3289
fc	2	8.11	4.06	6.44	0.0041
fa × fc	2	3.44	1.72	2.74	0.0784
fb × fc	4	6.44	1.61	2.56	0.0552
fa × fb × fc	4	1.78	0.44	0.71	0.5932

fa = Shape factor; fb = Cup size; fc = Peripheral speed of metering unit.

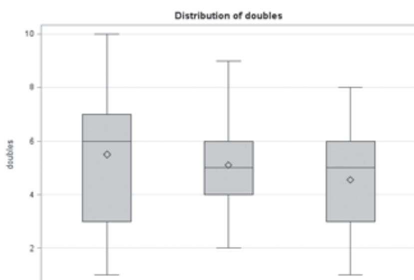
Fig. 4 Effect of different parameters on tuber doubles



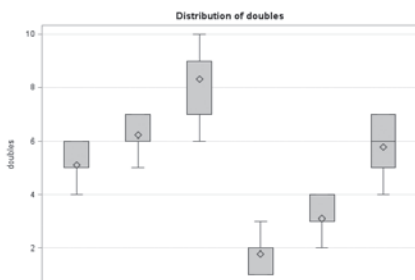
a. Effect of tuber shape factor on doubles



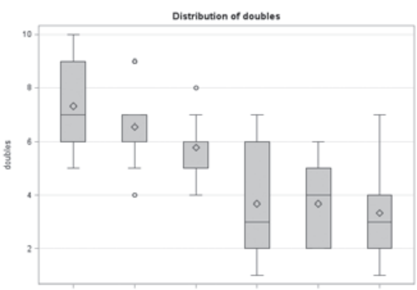
b. Effect of cup size on doubles



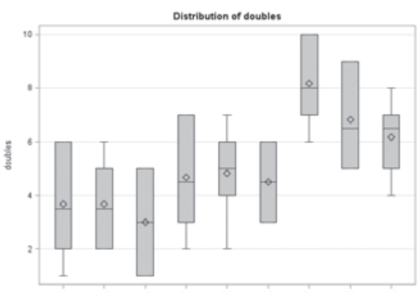
c. Effect of peripheral speed on doubles



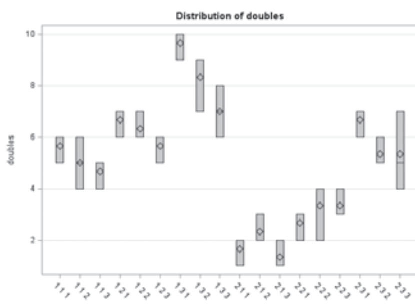
d. Interaction effect of tuber shape factor and cup size on doubles



e. Interaction effect of tuber shape factor and peripheral speed on doubles



f. Interaction effect of cup size and peripheral speed on doubles

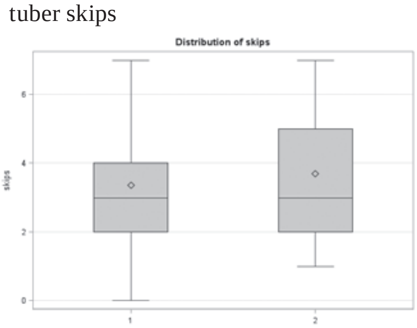


g. Interaction effect of shape factor, cup size and peripheral speed on doubles was obtained in medium sized cups than in small and large cups. It is because the size of cup influences the percent values of tuber doubles and skips. Consequently, the effect of increase or decrease in values of percent tuber doubles or skips directly have effect on CV% (**Fig. 3**). The large and small cups had either more tuber doubles or skips compared to medium cup. The medium cup relatively performed better, had 33.9% lesser tuber doubles than larger cup and 40.1% lesser tuber skips than small cup. Further it also had lesser CV than large and small cups. Thus, to achieve a maximum uniformity index i.e. uniform spacing of tubers within a furrow, it has select more irregular shaped tubers with medium sized cup (diameter of 54 mm and depth of 21 mm) and lower peripheral speed of metering unit. The similar kind of results were also obtained by researchers (Buitenwerf et al., 2006; Boydas and Uygan, 2012; Boydas, 2017).

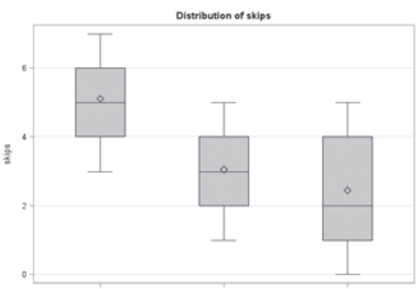
Conclusions

The tuber spacing uniformity within a planting furrow is very important to obtain higher tuber yield with efficient cultivation practices. Maintaining a uniform spacing between tubers is a very big challenging task and can only be achieved by tuber metering unit. The tuber doubles, skips and CV% decides the tuber metering efficiency of seed metering unit of belt planer. Using of more irregular shaped tubers particularly long shaped tubers in planter yield lesser CV% values. Likewise using medium sized spherical cups having dimensions of 54 mm in dia and 21 mm in depth gives 33.9% tuber doubles 40.1% lesser tuber skips with lower CV%. Operating of the metering unit at lower peripheral speed (0.21 to 0.35 m/s) gives better results and more uniform spaced tubers. Thus, to obtain higher uniformity index, long shaped tubers with medium sized cups at 0.21 to 0.35 m/s peripheral

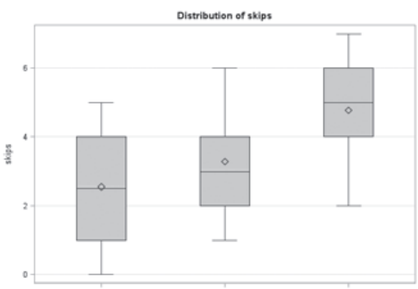
Fig. 5 Effect of different parameters on tuber skips



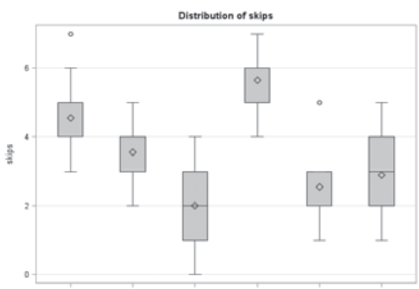
a. Effect of tuber shape factor on skips



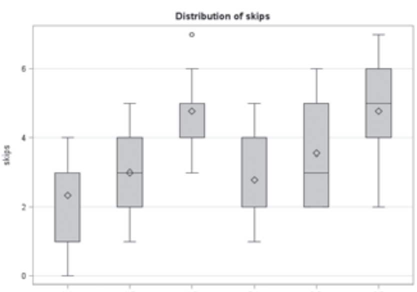
b. Effect of cup size on skips



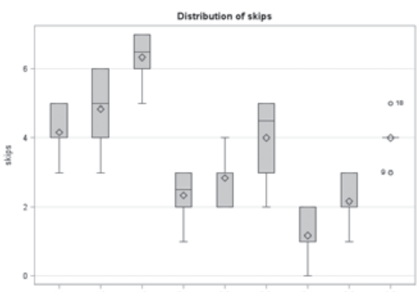
c. Effect of peripheral speed on skips



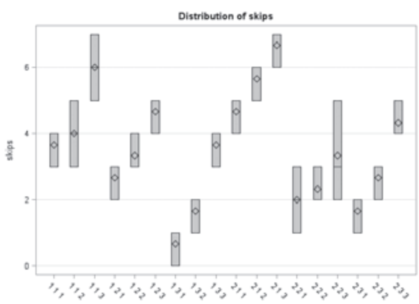
d. Interaction effect of tuber shape factor and cup size on skips



e. Interaction effect of tuber shape factor and peripheral speed on skips



f. Interaction effect of cup size and peripheral speed on skips



g. Interaction effect of shape factor, cup size and peripheral speed on skips

Table 5 ANOVA table to determine effect of different parameters on tuber skips

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
fa	1	1.50	1.50	2.70	0.1091
fb	2	70.26	35.13	63.23	< .0001
fa × fb	2	12.11	6.06	10.90	0.0002
fc	2	46.26	23.13	41.63	< .0001
fa × fc	2	0.78	0.39	0.70	0.5032
fb × fc	4	2.07	0.52	0.93	0.4556
fa × fb × fc	4	0.44	0.11	0.20	0.9367

fa = Shape factor; fb = Cup size; fc = Peripheral speed of metering unit.

speed of metering unit should be used.

REFERENCES

Al-Gaadi and S. A. Marey. 2011. Effect of forward speed and tuber characteristics on tuber spacing uniformity for a cup-belt potato planter. Middle-East Journal of Scientific Research, 8(4): 753-758.

Altuntaş, E. 2005. The effects of some operational parameters on potato planter's performance. Agricultural Mechanization in Asia, Africa and Latin America, 36(2): 87-91.

Anonymous. 2018. Horticultural statistics at a glance 2018. Horticulture Statistics Division, Department of Agriculture, Cooperation & Farmers' Welfare, Ministry of Agriculture & Farmers' Welfare, Government of India, pp. 458.

Anonymous. 2020. New planters in AVR Ceres series for planting 2 to 4 rows. Potato News Today. [https://www.potatonewstoday.com/2020/05/08/new-planters-in-avr-ceres-series-for-planting-2-to-4-rows/ (Accessed on 22.09.2020)].

Boydas, M. G. 2015. Effect of cup size, seed characteristics and angular speed on the performance of an automatic potato planter under laboratory. Tarimi bilimleri tergisi – Journal of Agricultural Sciences, 23: 317-327.

Boydas, M. G. and F. Uygan. 2012. Influence of Seed Physical Properties and Speed on the External Mechanical Damage Index and In-Row Spacing Uniformity in an Automatic Potato Planter. Tarim bilimleri tergisi – Jour. of Agri. Sci., 18: 126-136.

Buitenwerf, H., W. B. Hoogmoed, P. Lerink and J. Muller. 2006. Assessment of the behaviour of potatoes in a cup-belt planter. Biosystems Engineering, 95(1): 35-41.

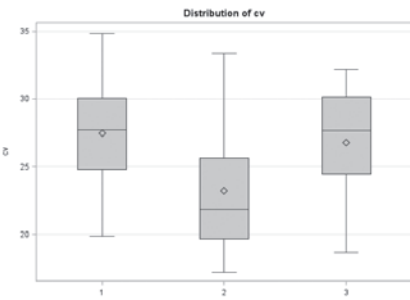
Bussan, A. J., P. D. Mitchell, M. E. Copas and M. J. Drilias. 2007. Evaluation of the effect of density on potato yield and tuber size distribution. Crop Sciences Society

Table 6 ANOVA table to determine effect of different treatments on CV%

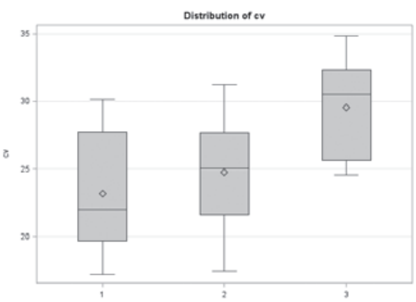
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
fa	1	38.41	38.41	13.62	0.0007
fb	2	187.65	93.82	33.27	< .0001
fa × fb	2	227.06	113.53	40.25	< .0001
fc	2	394.79	197.40	69.99	< .0001
fa × fc	2	87.55	43.78	15.52	< .0001
fb × fc	4	81.79	20.45	7.25	0.0002
fa × fb × fc	4	32.68	8.17	2.90	0.0354

fa = Shape factor; fb = Cup size; fc = Peripheral speed of metering unit.

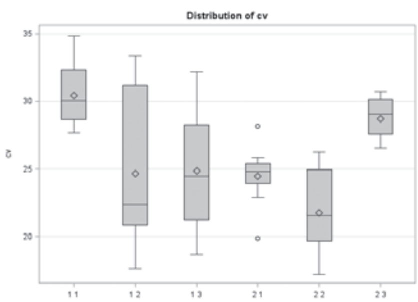
Fig. 6 Effect of different parameters on tuber CV%



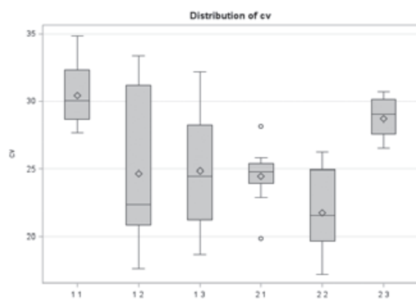
a. Effect of tuber shape factor on CV%



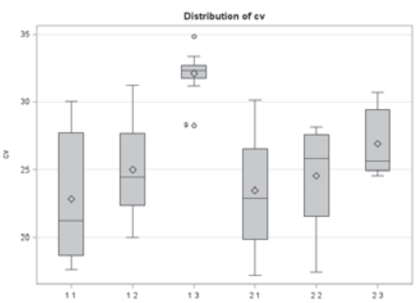
b. Effect of cup size on CV%



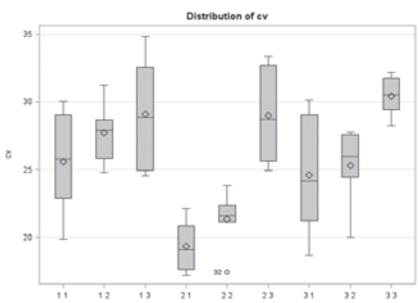
c. Effect of peripheral speed on CV%



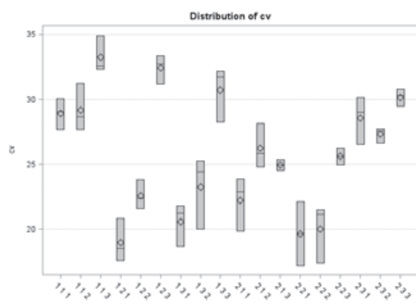
d. Interaction effect of tuber shape factor and cup size on CV%



e. Interaction effect of tuber shape factor and peripheral speed on CV%



f. Interaction effect of cup size and peripheral speed on CV%



g. Interaction effect of shape factor, cup size and peripheral speed on CV%

of America, 47: 2462-2472.
Chethan, C. R., V. K. Tewari, B. Nare and S. P. Kumar. 2018. Transducers for Measurement of Draft and Torque of Tractor-implement System – A Review. Agricultural Mechanization in Asia, Africa and Latin America, 49(4): 81-87.
Chethan, C. R., V. K. Tewari, A. K. Srivastava, S. P. Kumar, B. Nare, A. Chauhan and P. K. Singh. 2019. Effect of herbicides on weed control and potato tuber yield under different tuber eye orientations. Indian Journal of Weed Science, 51(4): 385-389.
Chethan, C. R., V. K. Tewari, A. K. Srivastava, B. Nare and S. P. Kunar. 2021. Planting of cut potato tubers in India and Global: Urgent need of planter mechanization to produce higher tuber yield. Significances of Bioengineering & Biosciences, 4(3): SBB. 000589. 2021. DOI: 10.31031/SBB.2021.04.000589
Güllüoglu, L. and H. Arioglu. 2009. Effects of seed size and in-row spacing on growth and yield of early potato in a Mediterranean-type environment in Turkey. African Journal of Agricultural Research, 4(5): 535-541.
Hardik, K. R. 2014. Development of mini tractor operated two row semi automatic potato planter. Published M.Tech thesis, Anand Agricultural University, Godhra, India.
IS: 11893-1986 (1987). Specifications for potato planter, semi-automatic. Bureau of Indian Standards. New Delhi, India, 1-12.
IS: 9856-1981 (1982). Test code for potato planters. Bureau of Indian Standards. New Delhi, India, 1-26.
James, W. C., R. H. E. Bradley, C. S. Smith and S. T. Wong. 1975. Misses in potato crops in New Brunswick in 1973; Their extent, distribution and cause. American Potato Journal, 52(3): 83-87.
Khairy, M. F. 1997. Performance evaluation of potato planter in sandy soil. Misr Journal of Agricultural Engineering, 14(1): 119-129.
Khurana, S. C., Y. S. Malik and M. L. Pandita. 1992. Herbicidal control of weeds in potato cv. Kufri Badshah-A note. Haryana J. Horti. Sci., 21 (3-4): 314-315.
Klassen, J. 1974. Potato planter speeds-how do they affect stand and production. In: Proceedings of the 13th Annual Washington State Potato Conference and Trade Fair, 29-31 January, Moses Lake, Washington, USA, pp. 71-74.
Klassen, J. 1975. Planter performance study. In: Proceedings of the 14th Annual Washington State Potato Conference and Trade Fair, 4-6 February, Moses Lake, Washington, USA, pp. 43-47.
Koning, de C. T. J., L. Speelman and H. C. P. de Vries. 1994. Size grading of potatoes: development of a new characteristic parameter. Journal of Agricultural Engineering Research, 57: 119-128.
Kutzbach, H. D. 1989. Influence of crop properties on the efficiency of agricultural machines and equipment. 4th International Conference on Physical Properties of Agricultural Materials, Rostock, Germany, September 4-8, pp 447-455.
McPhee J. E., B. M. Beattie, R. Corkrey and J. F. M. Fennell. 1996. Spacing uniformity-yield effects and in-field measurement. American Potato Journal, 73: 167-171.
Misener, G. C. 1979. Relative performance of cup and pick type potato planters. Canadian Agricultural Engineering, 21(2): 131-134.
Mohsenin, N. N. 1986. Physical Properties of Plant and Animal Materials. Gordon and Breach Science Publishers, New York. NY.
Pavek M. J. and R. E. Thornton. 2003. Poor planter performance: What's it costing the average Washington potato grower? In: Proceedings of the 42nd Annual Washington State Potato Conference and Trade Fair, 4-6 February, Moses Lake, Washington, USA, pp. 13-21.
Peer, Q. J. A., N. Ahmad, J. Kaur, M. H. Chesti, H. S. Ahmad, A. Bhat and B. A. Bhat. 2013. Study on economics of potato growing towards livelihood security. African journal of Agricultural Research, 8(45): 5639-5644.
Raghuvanshi, A., A. K. Gauraha and M. R. Chandrakar. 2018. Trends and economics of cultivation of potato in Chhattisgarh. Journal of Pharmacognosy and Phytochemistry, 7(3): 3150-3153.
Rupp, J. N. and R. E. Thornton. 1992. Seed placement and plant stand-is it worth worrying about? Proceedings of the 31st Annual Washington State Potato Conference and Trade Fair, 4-6 February, Moses Lake, Washington, USA. pp. 167-181.
Seyedbagheri, M. 2006. On-farm evaluation of potato planter performance. Available at https:// www. researchgate.net/publication/241015552_ON_ FARM_ EVALUATION_OF_POTATO_ PLANTER_ PERFORMANCE (Accessed date: 09 May 2021)
Tao, Y., C. T. Morrow, P. H. Heinemann and H. J. S. Ill. 1995. Fourier based separation technique for shape grading of potatoes using machine vision. Transactions of the ASAE, 38: 949-957.
Zo¨dler, H. 1969. Ermittlung des Formindex von Kartoffelknollen bei Legemachinenuntersuchungen. (Determination of the shape index of potato tubers in potato planter research), Grundlagen der Landtechnie, 15(5): 170.
Zoraki, M. and A. I. Acar. 2000. Optimum design of cup shape used in full automatic potato planter. Tarim Bilimleri Dergisi-Journal of Agricultural Sciences, 6(4): 135-140.

■■

Response Surface Modeling of Tillage Parameters for Draft Requirement of Three Tillage Implements Operating in Clay Loam Soil

by
Paul Okoko*
Dept. of Agricultural and Food Engineering,
Faculty of Engineering,
University of Uyo,
Uyo, NIGERIA
Corresponding author: okokokizito@gmail.com

Emmanuel A. Ajav
Dept. of Agricultural and Environmental Engineering,
Faculty of Technology,
University of Ibadan,
Ibadan, NIGERIA
eaajav@yahoo.co.uk

by
William Adebisi Olosunde
Dept. of Agricultural and Food Engineering,
Faculty of Engineering,
University of Uyo,
Uyo, NIGERIA
Corresponding author: okokokizito@gmail.com

Abstract

Tillage is a basic operation in agriculture and its energy requirements represent a considerable portion of the energy utilized in crop production. The trials were achieved using five tractor speeds (3.6, 5.4, 7.2, 9.0 and 10.8 km/h) and five tillage depths (10, 15, 20, 25 and 30 cm) to determine implement speed at different tillage depths for 3-bottom disc plough, spring tine cultivator and offset disc harrow in clay loam soil. The design of the experiment used two factors, five levels factorial of Central Composite Rotatable Design of Response Surface Method. Selected models were analyzed using ANOVA at α0.05 and also validated. The high values of the coefficient of determination for all the selected models and the close agreement between the predicted and experimental values show that the generated model equations can be used for prediction

Table 1 Specifications of tested tractor

Specification	Swaraj tractor, model 978 FE
Effective output (hp)	72 (53.7 kW)
Type of Engine	4 - cylinder
Type of Fuel	Diesel
Type of steering system	Power assisted
Type of injector pump	In-line injector
Fuel tank capacity (L)	98
Lifting capacity (kg)	1250
Rated engine speed (rpm)	2200
Type of cooling system	Water-cooled
Country of manufacture	China
Front tyres (size)	6.0-16
Inflation pressure (kPa)	360
Rear tyres (size)	14.9-28
Inflation pressure (kPa)	180

Table 2 Specifications of implements used during the field test

S/N	Item	Disc Plough	Tine Cultivator	Offset disc harrow
1	Type (Hitching)	Fully mounted	Fully mounted	Fully mounted
2	Number of bottoms / discs / Share blade	3	-	14
3	Number of tines	-	11	-
4	Width of tine (cm)	-	6	-
5	Type of disc blade	Plane concave	-	Plane Concave
6	Diameter of bottom/disc (cm)	65.3	7	62
7	Spacing of discs/share blade (cm)	68	10	22.5
8	Rake angle (°)	35	49	36
9	Width of implement (cm)	116	66	105
10	Actual width of cut (cm)	95.1	54.1	91.5
11	Disc angle (°)	45	-	25
12	Tilt angle (°)	20	-	15
13	Weight of implement (kg)	360	266	305

of draft requirement for the three tillage implements considered.

Keywords: Draft requirement, modeling, tillage, clay loam soil

Inroduction

A significant aspect of the overall cost in crop production is attributed to field machines. In order to minimize this overall cost of crop production, proper selection and matching of farm equipment is essential.

Montgomery (2005) and Raymond and Douglas (2002) stated that by combining statistical and mathematical tools, Response Surface Methodology is considered to be an effective methodology to develop, modify and optimize several operations. Data obtained from performance testing of tractors and implements are important for farm equipment operators and manufacturers alike as reported by Al – Suhaibani et al. (2010).

Loukanov et al. (2005) reported that draft requirements of an animal-drawn mouldboard plough are affected by the type of soil, soil moistures, speed of ploughing, depth and width of the furrow slice, type of the mouldboard used, as well as soil-to-metal friction characteristics of the soil-to-metal friction, the draft requirement of the plough can be reduced considerably.

Soil bin study was used by Manuwa and Ademosun (2007) to investigate the effects of moisture content and penetration resistance on draft force and soil disturbance of model tillage tools. The soil under investigation was a sandy clay loam. It was seen that the draft increased at a decreasing rate as the soil moisture content increased from 11 to 22.5% (d.b). The results also showed that the draft force was significantly affected by moisture content. In another development, draft force increased quadratically at an increasing rate with penetration resistance.

Joseph Odero et al. (2018) studied the effects of tillage depth and forward speed on draft power of primary tillage implements using a pull dynamometer in silt loam soil. They reported that there was significant increase in draft with increase in tillage depth and forward speed at all levels of the treatments tested. Anas and Osama (2015) carried out an investigation to determine the draft required for different implements under central Gezira clay soil conditions. They discovered that for both primary and secondary tillage operations, draft and fuel consumption of each tested implement significantly increased with increased operating speed and decreased with increased soil moisture content. Bikram et al. (2019) used a pull type cell with an auxiliary tractor to determine the draft requirement of selected implement. They observed that the draft requirement of mouldboard plough was maximum at 619 kgf compared to disc plough, disc harrow and cultivator.

The objectives of this research work are to: (i) develop regression equations for draft requirement for three implements on clay loam soil; and (ii) carryout statistical analysis.

Table 3 Mechanical properties of the soil at the study location for the tillage implements

Soil Parameter	Values		
	3-Bottom Disc Plough	Spring Tine Cultivator	Off-set Disc Harrow
Soil Composition (%)			
Sand	30	30	30
Silt	12	12	12
Clay	58	58	58
Classification	Clay loam	Clay loam	Clay loam
Average Bulk density (g/cm^3)	1.70	1.70	1.70
Average Moisture content (%)	13.94	14.26	16.15

Table 4 Experimental results for draft requirement using three implements on clay loam soil

S/N	Factor 1	Factor 2	D (kN)-3BDP	D (kN)-STC	D (kN)-ODH
	D_T (cm)	S_T (km/hr)			
1	10	7.2	1.51	0.16	1.35
2	15	5.4	2.52	0.26	2.15
3	15	9.0	2.68	0.29	2.35
4	20	3.6	3.69	0.39	3.04
5	20	7.2	3.93	0.40	3.19
6	20	7.2	3.90	0.40	3.18
7	20	7.2	3.91	0.40	3.19
8	20	7.2	3.92	0.40	3.18
9	20	7.2	3.90	0.40	3.19
10	20	10.8	4.03	0.41	3.27
11	25	5.4	5.61	0.53	4.23
12	25	9.0	5.90	0.56	4.39
13	30	7.2	8.66	0.70	5.53

D_T = Tillage Depth (cm); S_T = Tractor Speed (km/hr); D = Draft requirement (kN); 3BDP = 3-Bottom Disc Plough; STC = Spring Tine Cultivator; ODH = Offset Disc Harrow

Material and Methods

2.1 Study Location

The study was conducted at the Department of Agricultural and Food Engineering demonstration farm in the University of Uyo located in Uyo local government area of Akwa Ibom state, Nigeria.

2.2 Tractor and Tillage Implements

The specification of the tractor used in all the field experiments is presented in **Table 1**. A 3-bottom disc plough, an offset disc harrow, and a spring tine cultivator were used in this research work for evaluating draft and requirement over a wide range of tractor speeds and tillage depths. Implement specifications are given in **Table 2**.

2.3 Determination of Draft Requirement

The draft of all the tillage implements was determined using the equation as given by Ejit et al. (2006).

$$D = W + [c(bd/\sin\beta) + \rho bdv_o^2 \sin\delta/\sin(\delta+\beta)] / [Z(\sin\beta + \mu\cos\beta)] \quad (1)$$

Where,

D = Draft requirement of tillage implements, kN

W = Weight of soil, kN

C = Soil cohesion, kPa

μ = coefficient of internal soil friction

β = angle of the forward failure surface, deg.

V_o = speed of operation, m/s

$$Z = [(\cos\delta - \mu'\sin\delta) / (\sin\delta + \mu'\cos\delta)] + [(\cos\beta - \mu\sin\beta) / (\sin\beta + \mu\cos\beta)] \quad (2)$$

μ' = coefficient of internal soil – metal friction

2.4 Experimental Design

The design of experiment involved two factors, five levels, factorial central composite rotatable design (CCRD) of response surface methodology. Five levels of tillage depths (10, 15, 20, 25 and 30 cm) and tractor speeds (3.6, 5.4, 7.2, 9.0 and 10.8 km/h) were chosen.

An experimental plot of 100 m long and 50 m wide was used for each implement. A plot of 50 m by 50 m was used as a practice area before the beginning of the experimental runs to enable the tractor and the implement to reach the selected tractor speed and tillage depth. Tillage depth was measured as a vertical distance from the top of the undisturbed soil surface to the implements deepest penetration using a steel measuring tape. The different tractor speeds (3.6-10.8 km/h) were achieved by selecting appropriate gears and adjusting engine throttle at engine speeds of 1,600-2,000 rpm while the tillage depths of (10-30 cm) were achieved by using tractor depth controller through its quadrant. Time taken for each implement to travel a distance of 100 m was taken and recorded. The distance was divided by the time taken to obtain the implement travel speed.

2.5 Model selection for the Dependent Variables

In selecting a model, the polynomial with the highest order and the additional terms in the polynomial are significant, and the model is not aliased, lack-of-fit is not significant, and the maximization of the "Adjusted R^2" and the "predicted R^2" were considered. The cubic model is aliased and cannot be selected, and when the coefficient of determination (R^2) is maximum, and the value of standard deviation is minimum. A Design Expert (version 11.0.1) software package for the design of experiments was utilized to study

Table 5 Model comparison for t draft requirement for 3-bottom disc plough at the study location

Models	Linear	2FI	Quadratic	Cubic
Std. Dev.	0.4821	0.5077	0.1314	0.0160
R^2	0.9386	0.9387	0.9968	1.0000
Mean	4.17	4.17	4.17	4.17
Adjusted R^2	0.9263	0.9182	0.9945	0.9999
C.V.	11.57	12.19	3.15	0.3841
Predicted R^2	0.8404	0.8361	0.9677	0.9981
PRESS	6.04	6.20	1.22	0.0707
Adequate precision	29.67	24.39	76.95	569.62

Table 6 Model comparison for draft requirement for spring tine cultivator at the study location

Models	Linear	2FI	Quadratic	Cubic
Std. Dev.	0.0130	0.0137	0.0064	0.0019
R^2	0.9923	0.9923	0.9987	0.9999
Mean	0.4077	0.4077	0.4077	0.4077
Adjusted R^2	0.9908	0.9898	0.9978	0.9998
C.V.	3.20	3.37	1.56	0.4555
Predicted R^2	0.9812	0.9793	0.9872	0.9909
PRESS	0.0042	0.0046	0.0028	0.0020
Adequate precision	86.28	70.89	124.81	370.70

Table 7 Model comparison for draft requirement for offset disc harrow at the study location

Models	Linear	2FI	Quadratic	Cubic
Std. Dev.	0.1087	0.1144	0.0329	0.0288
R^2	0.9910	0.9910	0.9994	0.9997
Mean	3.25	3.25	3.25	3.25
Adjusted R^2	0.9892	0.9881	0.9990	0.9992
C.V.	3.37	3.52	1.01	0.8873
Predicted R^2	0.9773	0.9764	0.9953	0.9643
PRESS	0.2985	0.3109	0.0625	0.4692
Adequate precision	79.63	65.54	186.17	184.82

FI = Factorial Interaction; Std. Dev. = Standard deviation; C.V. = Coefficient of Variation; PRESS = Predicted Sum of Square.

and to generate model equations for the dependent variables for all the tillage implements.

Results and Discussion

3.1 Soil Analysis Test for the Study Location

Analysis of soil test was carried out at the study location for the three tillage implements. The results of the analysis test for mechanical properties of the soil are presented in **Table 3**.

3.2 Experimental Test Results

Summary of the experimental results for the two factors, five levels factorial Central Composite Rotatable Design (CCRD) of the response surface methodology (RSM) for draft requirement is presented in **Table 4**.

3.3 Model Selection for the Tillage Operation for Draft Requirement at the Study Location

The comparison of the linear, 2FI, quadratic and cubic models for the draft requirement for 3-bottom disc plough, spring tine cultivator and offset disc harrow at the study location is presented in **Tables 5**, **6** and **7** respectively. Considering the model with the maximum R^2 value and the minimum standard deviation (with preference given to R^2), quadratic, quadratic and quadratic models were selected to predict the draft requirement of tillage operation for 3-bottom disc plough, spring tine cultivator and offset disc harrow respectively. The final regression equations for the draft requirement for 3-bottom disc plough, spring tine cultivator and offset disc harrow are given in Equations 3, 4 and 5 as:

$$D_{3-BDP} = 1.66 - 0.15D_T + 0.039S_T + 0.0036D_TS_T + 0.012D_T - 0.0041S_T^2 \quad (R^2 = 0.9968) \tag{3}$$

$$D_{STC} = -0.051 + 0.015D_T + 0.0044S_T + 3.45 \times 10^{-18}D_TS_T + 0.00030D_T^2 - 0.000013S_T^2 \quad (R^2 = 0.9987) \tag{4}$$

$$D_{ODH} = -0.48 + 0.11D_T + 0.092S_T + 0.0011D_TS_T + 0.0026D_T^2 - 0.0022S_T^2 \quad (R^2 = 0.9994) \tag{5}$$

Where,

D_{3-BDP} = Draft requirement for 3-bottom disc plough, kN

D_{STC} = Draft requirement for spring tine cultivator, kN

D_{ODH} = Draft requirement for offset disc harrow

kN; D_T = Tillage Depth, cm

S_T = Tractor Speed, km/h

The ANOVA for the selected models for the draft requirement for 3-bottom disc plough, spring tine cultivator and offset disc harrow at the study location is presented in **Tables 8**, **9** and **10** respectively.

Table 8 Analysis of Variance for response surface quadratic model for draft requirement for 3-bottom disc plough at the study location

Source of Variation	Sum of squares	df	Mean Square	F-Value	p-value
Model	37.71	5	7.54	436.65	< 0.0001
D_T	35.40	1	35.40	2049.55	< 0.0001
S_T	0.1064	1	0.1064	6.16	0.0421
$D_T \times S_T$	0.0042	1	0.0042	0.2446	0.6360
D_T^2	1.97	1	1.97	113.89	< 0.0001
S_T^2	0.0040	1	0.0040	0.2331	0.6440
Residual	0.1209	7	0.0173		
Lack of Fit	0.1202	3	0.0401	235.72	< 0.0001
Pure Error	0.0007	4	0.0002		
Cor Total	37.83	12			

Table 9 Analysis of Variance for response surface quadratic model for the draft requirement for spring tine cultivator at the study location

Source of Variation	Sum of squares	df	Mean Square	F-Value	p-value
Model	0.2209	5	0.0442	1089.53	< 0.0001
D_T	0.2187	1	0.2187	5392.24	< 0.0001
S_T	0.0008	1	0.0008	20.55	0.0027
$D_T \times S_T$	0.0000	1	0.0000	0.0000	1.0000
D_T^2	0.0013	1	0.0013	32.14	0.0008
S_T^2	4.257E-08	1	4.257E-08	0.0010	0.9751
Residual	0.0003	7	0.0000		
Lack of Fit	0.0003	3	0.0001		
Pure Error	0.0000	4	0.0000		
Cor Total	0.2212	12			

Table 10 Analysis of Variance for response surface quadratic model for the draft requirement for offset disc harrow at the study location

Source of Variation	Sum of squares	df	Mean Square	F-Value	p-value
Model	13.15	5	2.63	2,430.35	< 0.0001
D_T	12.98	1	12.98	11,997.62	< 0.0001
S_T	0.0560	1	0.0560	51.80	0.0002
$D_T \times S_T$	0.0004	1	0.0004	0.3697	0.5623
D_T^2	0.0943	1	0.0943	87.19	< 0.0001
S_T^2	0.0012	1	0.0012	1.06	0.3364
Residual	0.0076	7	0.0011		
Lack of Fit	0.0075	3	0.0025	82.81	0.0005
Pure Error	0.0001	4	0.0000		
Cor Total	13.15	12			

[a]Significance; D_T represents tillage depth (cm); S_T represents tractor speed (km/hr)

For 3-bottom disc plough, the probability value of 0.0001 (**Table 8**) of the model is less than the selected α-level of 0.05. This implies that the model chosen is significant. The probability values of 0.0001, 0.0421 and 0.0001 (**Table 8**) of the model expressions are less than the selected α-level of 0.05. This indicates that model expressions are significant. In line with this, D_T, S_T and D_T^2 are significant model terms. It was established that the model was significant with an acceptable coefficient of determination (R^2 = 0.9968), which shows an excellent correlation between the tillage depth and tractor speed. This value specifies that the model for the draft requirement for 3-bottom disc plough at the study location can describe 99.68% of the whole variability in the responses.

For spring tine cultivator, the probability value of 0.0001 (**Table 9**) of the model is less than the selected α-level of 0.05. This shows that the model selected is significant. The probability values of 0.0001, 0.0027 and 0.0008 (**Table 9**) of the model expressions are less than the selected α-level of 0.05. This specifies that the model expressions are significant. In view of this, D_T, S_T and D_T^2 are the significant terms. It was also established that the model was significant with the coefficient of determination (R^2 = 0.9987), implying that there are excellent correlations between the tillage depth and tractor speed. This value specifies that the model for the draft requirement for spring tine cultivator at the study location can describe 99.87% of the variability of the responses.

For offset disc harrow, the probability value of 0.0001 (**Table 10**) of the model is less than the selected α-level of 0.05. This shows that the model selected is significant. The probability values of 0.0001, 0.0002 and 0.0001 (**Table 10**) of the model expressions are less than the selected α-level of 0.05. This denotes that the model expressions are significant. In line with this, D_T, S_T and D_T^2 are the significant terms. It was established that the model was significant with the coefficient of

Table 11 Experimental, Predicted, Residual, and Standard residual values of draft requirement for 3-bottom disc plough at the study location

S/N	D_T (cm)	S_T (km/h)	Experimental values	Predicted values	Residual values	Standard Residual
1	10	7.2	1.5100	1.6449	-0.1349	-2.24
2	15	5.4	2.5200	2.4085	0.1115	1.19
3	15	9.0	2.6800	2.5318	0.1482	1.59
4	20	3.6	3.6900	3.6666	0.0234	0.39
5	20	7.2	3.9300	3.9079	0.0221	0.18
6	20	7.2	3.9000	3.9079	-0.0079	-0.07
7	20	7.2	3.9100	3.9079	0.0021	0.02
8	20	7.2	3.9200	3.9079	0.0121	0.10
9	20	7.2	3.9000	3.9079	-0.0079	-0.07
10	20	10.8	4.0300	4.0432	-0.0132	-0.22
11	25	5.4	5.6100	5.7785	-0.1685	-1.80
12	25	9.0	5.9000	6.0318	-0.1318	-1.41
13	30	7.2	8.6600	8.5149	0.1451	2.41

Table 12 Experimental, Predicted, Residual, and Standard residual values of draft requirement for spring tine cultivator at the study location

S/N	D_T (cm)	S_T (km/h)	Experimental values	Predicted values	Residual values	Standard Residual
1	10	7.2	0.16000	0.16086	-0.00086	-0.30
2	15	5.4	0.26000	0.26494	-0.00494	-1.09
3	15	9.0	0.29000	0.28161	0.00839	1.85
4	20	3.6	0.39000	0.38420	0.00580	1.99
5	20	7.2	0.40000	0.40069	-0.00069	-0.12
6	20	7.2	0.40000	0.40069	-0.00069	-0.12
7	20	7.2	0.40000	0.40069	-0.00069	-0.12
8	20	7.2	0.40000	0.40069	-0.00069	-0.12
9	20	7.2	0.40000	0.40069	-0.00069	-0.12
10	20	10.8	0.41000	0.41753	-0.00753	-2.58
11	25	5.4	0.53000	0.53494	-0.00494	-1.09
12	25	9.0	0.56000	0.55161	0.00839	1.85
13	30	7.2	0.70000	0.70086	-0.00086	-0.30

Table 13 Experimental, Predicted, Residual, and Standard residual values of draft requirement for offset disc harrow at the study location

S/N	D_T (cm)	S_T (km/h)	Experimental values	Predicted values	Residual values	Standard Residual
1	10	7.2	1.3500	1.3732	-0.0232	-1.54
2	15	5.4	2.1500	2.1353	0.0147	0.63
3	15	9.0	2.3500	2.2920	0.0580	2.48
4	20	3.6	3.0400	3.0315	0.0085	0.56
5	20	7.2	3.1900	3.1966	-0.0066	-0.22
6	20	7.2	3.1800	3.1966	-0.0166	-0.55
7	20	7.2	3.1900	3.1966	-0.0066	-0.22
8	20	7.2	3.1800	3.1966	-0.0166	-0.55
9	20	7.2	3.1900	3.1966	-0.0066	-0.22
10	20	10.8	3.2700	3.3049	-0.0349	-2.31
11	25	5.4	4.2300	4.2353	-0.0053	-0.23
12	25	9.0	4.3900	4.3520	0.0380	1.63
13	30	7.2	5.5300	5.5332	-0.0032	-0.21

determination (R^2 = 0.9994). This value pointed out that the model equation for the draft requirement for offset disc harrow at the study location can describe 99.94 % of the variability of the responses.

3.4 Model Validation for Draft Requirement in Tillage Operations at the Study Location

A test run under the obtained optimal tillage operating parameters for draft requirement for 3-bottom disc plough, spring tine cultivator and offset disc harrow at the study location was carried out in order to evaluate the precision of the quadratic, quadratic and quadratic models for draft for 3-bottom disc plough, spring tine cultivator and offset disc harrow respectively. Comparing the experimental and predicted results (**Tables 11**, **12** and **13**) for the draft requirement for 3-bottom disc plough, spring tine cultivator and offset disc harrow at the study location, it was observed that the deviations between the experimental and predicted values of the draft requirement were low and ranged between 0.01 to 0.10 for 3-bottom disc plough, 0.01 to 0.02 for spring tine cultivator, and 0.01 to 0.13 for offset disc harrow, respectively. This indicates that the predicted and the experimental values are in close agreement and the generated model can be used satisfactorily to predict the draft requirement (kN) for the tillage operation.

Conclusions

Model equations were generated with a satisfactory coefficient of determination (R^2) for two factors for draft requirement for 3-bottom disc plough, spring tine cultivator and offset disc harrow on a clay loam soil. There is high coefficient of determination for draft requirement. The predicted and the experimental values are in close agreement. These show that the generated models can be used satisfactorily to predict draft requirement on a clay loam type of soil for the three tillage implements. The Analysis of Variance (ANOVA) $\alpha_{0.05}$ for the selected models for all the implements showed that the models chosen are significant.

REFERENCES

Al-Suhaibani, A. A., Y. N. Al-Janobi and B. Al-Majhadi. 2010. Development and evaluation of tractors and tillage implement instrumentation system. American Journal of Engineering and Applied Sciences, 32: 363-371.

AnasDAbdAllahMohammed, A. A and A. M. Osama. 2015. Determination of draft power requirements for tillage implements under central Gezira clay soil conditions. SUST Journal of Agricultural and Veterinary Sciences 16(2): 20-24.

Bikram Jyoti, K. V. S. Ram Reddy, P. S. Chetankumar and A. P. Pandirwar. 2019. Predicting draft requirement of tillage implements using pull type load cell in southern region of Andhra Pradesh, India. International Journal of Current Microbiology and Applied Sciences 9(1): 606-611.

Ejit, K. S., E. G. Carroll, P. R. Roger and R. B. Dennis. 2006. Engineering Principles of Agricultural Machines. 2nd Edition, John Wiley and Sons Inc., USA.

Joseph, O. A., M. N. N. Godfrey and R. N. Musa. 2018. Effects of depth and speed on power requirements for disc and mouldboard ploughs in silt loam soils. International Journal of Scientific and Technology Research 7(8): 167-174.

Loukanov, A., J. Uziak and J. Michalek. 2005. Draught requirements of enamel coated animal-drawn mouldboard plough. Journal of Research in Agricultural Engineering. 51(2): 56-62.

Manuwa, S. I. and O. C. Ademosun. 2007. Draught and soil disturbance of model tillage tines under varying soil parameters. Agricultural engineering international. The CIGR Ejournal. 9(6): 1-18.

Montgomery, D. C. 2005. Design and analysis of experiments. Response surface method and designs. John Wiley and Sons, Inc.: Hoboken, NJ, USA.

Raymond, H. M. and M. C. Douglas. 2002. Response surface methodology: Process and product optimization using designed experiments, and ed.; John Wiley and Sons, Inc.; Hoboken, NJ, USA.

Ojhai, T. P. and A. M. Micheal. 2006. Principles of agricultural engineering. 6th Edition. New York. McGraw-Hill.

■■

Tractor Rear Tyre Wear Rate during Highway Travel in Ghana

by
S. Y. Dorvlo
Dept. of Agricultural Engineering,
University of Ghana,
Legon, Accra, GHANA
sydorvlo@yahoo.com

A. A. Mahama
Dept. of Agricultural Engineering,
University of Ghana,
Legon, Accra, GHANA

E. A. Baryeh
Dept. of Agricultural Engineering,
University of Ghana,
Legon, Accra, GHANA

Abstract

The tractor, which is a major source of farm power, is not only used for on-farm work but also for hauling goods over long distances from most Ghanaian farms. The use of the tractor for off-farm activities results in severe wear of the tractor tyres most especially the rear tyre. It has however, been noted that farmers in Ghana find it difficult to acquire and replace worn out rear tractor tyres. This study seeks to understand and provide information on the tractor rear tyre wear during highway travel, since for this form of transportation the farmer can get alternatives. Consequently, a 55.9 kW (75HP) Massey Furguson 375E wheel tractor fitted with 18.4-30 new tyres marked at four diametrically opposite sides was used for the study. Wear measurements (change in tyre lug height) were taken using a Vernier caliper (depth gauge) while a distance measuring auxiliary wheel was used to measure the distance travelled and a pressure gauge was used to ensure constant tyre pressure during the experiments. From each tyre, eight lugs were assessed at three points and the twenty-four wear measurements obtained were statistically analyzed. The average wear rate found was 10.65 ± 1.07 × 10^{-4} mm/km. The findings of the study showed that to prevent severe wearing of the rear tyre, highway travel with the rear tyre should be done only when there are no alternatives to highway travel.

Keywords: Tractor, rear tyre, wear rate, tyre lugs, highway travel

Introduction

The use of the agricultural wheel tractor has increased in the country over the past years due to the increased need for mechanization. The agricultural tractor as a power source on the farm has several uses due to its flexibility. The agricultural wheel tractor has the functionality to be hitched to other farm equipment and aid in land preparation, planting, harvesting, and threshing. Also, the agricultural wheel tractors have the capacity to carry heavy loads. As such many farmers who own the agricultural tractor not only use it for work on the farm but also for hauling their products and goods. This often leads to traveling over long distances within the farm vicinity or on the farm.

During travelling the agricultural tractor must provide enough traction to be able to move effectively. The most important feature on the agricultural tractor that assists in the provision of the necessary traction is the four pneumatic wheels it has. According to Wulfsohn & Way (2009), traction is a result of the friction and adhesion between the surfaces in contact; the tyre and road surface. Most agricultural tractor tyres are optimized for field work hence any other use will put pressure on the tyre beyond its required lifespan.

Nonetheless, not all the wheels of the tractor tyre undergo the same level of friction and adhesion. According to Cassady (1997), the tractor rear tyre carries more weight than the front tyres due to the weight distribution of the tractor tyre. This implies that the tractor rear tyres undergoe more friction, hence will wear more. In Ghana, rear tyres are problematic for tractor owners to maintain. This was confirmed by Mahama et al., (2004), in their study on maintenance of tractors in Ghana where rear tyres were observed to be the most difficult part to replace when worn out and often leads to lots of tractors being placed on platforms.

Car tyres as well as tractor tyres undergo some considerable amount of wear when used on hard contact surfaces. In a study conducted by Lupker et al., (2002), the tread depth loss at the front and rear axles of the trucks tested were 15,000 km/mm to 30,000 km/mm and 10,000 km/mm and 15,000 km/mm respectively. When the results from Lupker et al., (2002) was compared with the results obtained for tractor rear tyres during ploughing by Dorvlo et al., (2014), it was observed that tactor rear tyres undergo more severe wear than truck tyres.

It is therefore necessary to investigate the possible wear scenario that will occur if the tractor rear tyre is used under off-farm conditions. As such this study will determine the wear rate of the tractor rear tyre under off-farm conditions in Ghana and also provide data to aid in effective planning of rear tyre use and replacement.

In Ghana, there are different categories of roads. There are roads paved with concrete slabs, roads paved with marbles and bitumen and roads that are covered with soil and then compacted. Although most farmers do not have tarred or paved roads on their farms, the form of transportation considered in this study was the use of the tractor for travelling on the highways. Firstly, this is due to the fact that, this form of transportation is the one that will be of most concern to the farm machinery owner when he has to haul farm inputs or products to and from the farm, since most farming communities and the market centers the farmer will need to go to are linked by highways. Secondly, the farmer can obtain an alternate means of transport for his goods outside the farming community.

Therefore, the objective of this study is to evaluate the wear of the rear tyre when using the tractor as a means of transportation on the highway and provide appropriate data on the wear rate of the agricultural tractor rear tyre during highway travel in Ghana. This will also add up to the literature on tyre wear since there is very few studies on this in literature.

Materials and Methods

To attain the aim of the study, a 45 km stretch of the highway from Accra to Aflao was selected for the field experiment. This highway is paved with marbles and bitumen which is the composition of most highways in the country; therefore, it is representative of the highway road network in the country. A Google map view of the road is shown in **Fig. 1**. The total distance for the field experiment was 90 km, and this is attained when the tractor travels back and forth on the selected portion of the road. There was no significant difference between the ambient temperatures for the test days or times during the highway tests.

A 55.9 kW (75 HP) Massey Ferguson 375E wheeled tractor fitted with new tyres (18.4-30) was used for the study. Tyre lug height was measured using the vernier caliper (depth gauge), an auxiliary distance-measuring wheel was used for distance measuring, the pressure gauge was used to ensure a constant tyre pressure for all tests whiles the stopwatch was used for measuring the time during the slip determination. During the wear evaluation each measurement was taken three times and then statistically analysed with the Excel software of the Microsoft office package. Since tyre wear is affected by the surfaces in contact, the slip during the field test was also measured.

Slip Measurement

Traction is a result of two surfaces in contact and the efficiency of the traction attained is dependent on the nature of the two surfaces. Slip on the other hand quantifies the reduction in the efficiency of the traction being provided based on the surfaces in contact. Therefore, the slip of the tractor rear tyre during highway travel was determined.

This was determined by using a stop watch to measure the time it takes for the tractor to move a kilometer. During the highway travel experiment a constant speed of 40 km/h was observed. Therefore, the theoretical time that it takes a tractor travelling at a constant speed of

Fig. 1 Google map view of the Accra-Aflao highway used for the off-farm experiment

(Source: http://maps.google.com.gh/)

40 km/h to cover one kilometer is 90 seconds. This was recorded as the value of Tn in Equation 1. The practical time it took the tractor to travel one kilometer was measured and recorded as T_l. After obtaining these values, Equation 1 stated below was used to obtain the percentage slip measured for each test.

$$slip\ (\%) = [(T_l - T_n) / T_l] \times 100\% \quad (1)$$

Wear and Wear Rate Determination

The method described by Dorvlo et al., (2014) was used for determining the wear and wear rate in this study, which has been briefly stated.

Each test involved running the tractor for a specific distance on the highway and then measuring the corresponding wear from the points selected on each lug (**Fig. 2**). After obtaining the lug height measurements and determining the total distance traveled during a specific test, wear (W_H), the rate of wear (W_R) for each test was determined with the following equations from Dorvlo et al., (2014);

$$W_H\ (mm) = H_b - H_a \quad (2)$$

$$W_R\ (mm/km) = \Delta W_H\ (mm) / T_D\ (km) \quad (3)$$

Where,

H_a = lug heihgt after a specific task

H_b = lug height before a specific task

T_D = total distance travelled during a test

W_R = wear rate

W_H = average wear rate during a test

This was done for each set of lugs at the four selected sections shown on the rear tyre (**Fig. 2a**) for both the right and left tyres. The total wear for each test was recorded as the average wear of each lug for both rear tyres. During each test run, twenty-four readings were recorded for each of the left and right tyres. A total of three tests were done and the average wear that occurred for all the three tests was recorded for further statistical analysis.

Since the total distance travelled during each of the experiment was needed to calculate the wear rate during each test; the tractor odometer was used to measure the total distance travelled during each experiment. To obtain a distance measurement to the nearest one meter, a distance measuring wheel was attached to the back of the tractor (**Fig. 3**). Since the distance measuring wheel can measure up to 9,999 m, it was possible to measure the distance travelled to the nearest meter. The distance obtained was used in Equation 3 to obtain the wear rate for each experiment.

Table 1 Percentage slip measured for the off-farm test

Experiment	Time required to travel 1 km at 40 km/h, T_n (s)	Time used to travel 1 km at 40 km/h, T_l (s)	Slip (%)
1	90	114.70	21.53
2	90	116.23	22.57
3	90	115.02	21.53
Average ($\bar{x}$)			21.88
Standard Deviation $\sqrt{\frac{1}{n}\sum_{i=1}^{n}(Slip_i - \bar{x})^2}$			21.88

Results and Discussion

Slip Measurement

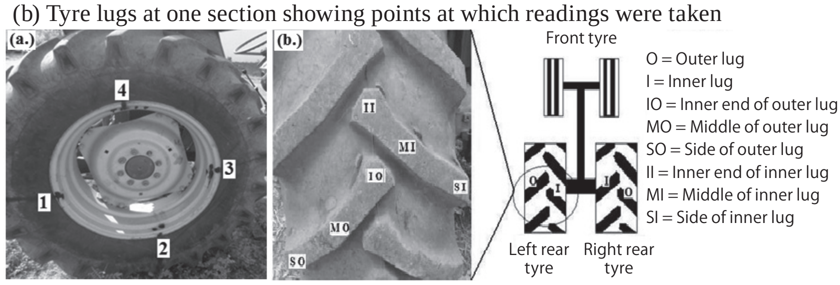
Table 1 contains the slip measured during the experiments and on the average the reduction in the efficiency of traction during the highway experiment was 21.88 ±0.54%.

Wear and Wear Rate

A total of eight lugs were selected from both the left and right tyre and the wear was measured at their side, middle and inner part during the field tests. The average values of the wear measured and the wear rates calculated are shown in **Table 2**.

From the final results attained it was seen that during highway travel with the tractor, the rear tyre wears at an average rate of $10.65 \pm 1.07 \times 10^{-4}$ mm/km. Taking into consideration this average wear rate, when

Fig. 2 (a) Rear tyre with four sections (1, 2, 3, and 4) marked for easy data recording. (b) Tyre lugs at one section showing points at which readings were taken



(Source: Dorvlo et al., 2014)

Fig. 3 Distance travel measurement with wheel odometer aggregation

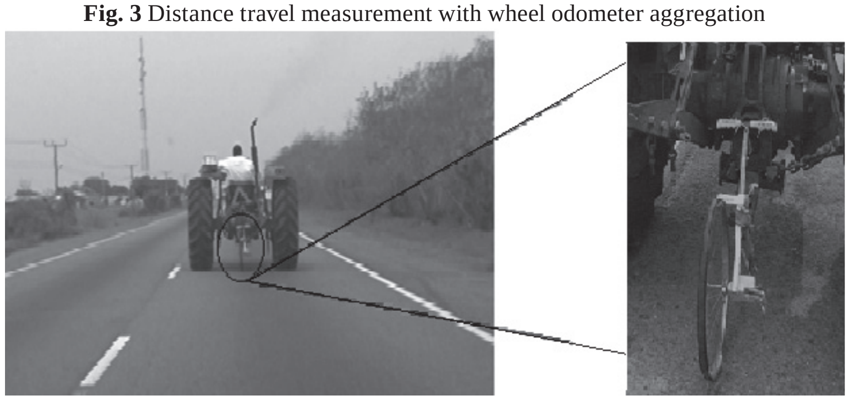


Table 2 Average values of wear and wear rate for the rear tyre during the off-farm test

Property / Replicates	Test 1	Test 2	Test 3
Average wear, ΔW_H ($\times 10^{-3}$ mm)	32.5 ± 3.9	30.4 ± 3.3	32.9 ± 2.5
Total Distance, T_D (km)	30.00	30.00	30.00
Wear rate, W_r ($\times 10^{-4}$ mm/km)	10.83 ± 1.29	10.14 ± 1.10	10.97 ± 0.83
Average wear rate, W_{rx} ($\times 10^{-4}$ mm/km)		10.65 ± 1.07	

Table 3 Statistical analysis of wear data at different locations of the lug

Source of Variation	SS	df	MS	F	P-value	F crit
WR	1.94×10^{-5}	3	6.48×10^{-5}	1.75	0.25	4.75
WC	6.52×10^{-3}	2	3.26×10^{-3}	880.75	3.91×10^{-8}	5.14
Error	2.22×10^{-5}	6	3.70×10^{-6}			
Total	6.56×10^{-3}	11				

WR = wear data for outer and inner lug of each tyre; WC = wear data for left and right tyre; SS = Sum of Squares; df = degree of freedom; MS = Mean Square; F = calculated F-test value; P-value = probability value; F crit = F-test value from Fisher's distribution table.

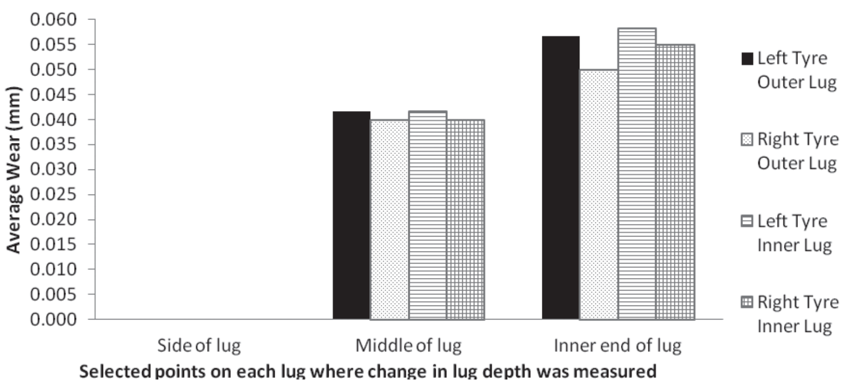
using the rear tyre for highway travel, each time a millimeter of the rear tyre's lug height wears off, a distance of travel between 853.24-1,043.84 km will be covered.

A comparison of the above wear results with wear results obtained for tractor rear tyres during ploughing (Dorvlo et al., 2014) showed that the tractor rear tyre wears more during highway travel than during ploughing. Since tyre wear is dependent on the efficiency of traction, it is proposed that the difference in wear is a result of the difference in efficiency which is due to the nature of the surface in contact with the tyre during use under the two conditions. The road is a firmer surface than the soil. Conversely, the tractor carried more load (3 bottom plough and operator) during the ploughing test compared to the load carried during the highway test. But then, it could also mean that the contact patch a tyre makes does not affect the severity of wear, since the tyre will have a larger contact surface during the ploughing experiment than during the highway experiment.

Wear Distribution on Lugs and Tyres

The wear distribution on the lugs is summarized in **Figure 4**. The average wear measurements obtained from the middle of the lug and the inner end of the lug show different levels of variations at the various locations where wear was measured but the side of the lug had no wear values recorded. In ascending order of average wear measured, the side of the lug comes first followed by the middle of the lug and then the inner part of the lug. The inner portion of each individual lug had an average value of 28% more wear than the middle of the lug whiles no wear was recorded for the side of the lug.

Fig. 4 Bar graph for the wear recorded at each point on each lug during the off-farm test



A careful look at the cross-section of the tyre when it is in contact with the road gives an insight into the possible reason for the no change in lug height (wear) at the side of the tyre during off-farm use. It can be put forward that the tyre makes contact with the road at the inner end of the lug and the middle of the lug hence the resulting wear at such points. Yap (1989) proposed that increased load and inflation pressure can affect the tyres foot prints at the sides and the tyres contact patch. Since the tyre did not carry any load other than the tractor operator, and the inflation pressure of the tyre was at the optimum required, it suggests that there should be no wear at the side of the tyre as observed in the study. However, when Lupker et al., (2002) experienced severe wear at the side of the tyre on the trucks they used in their study, they suggested that the wear was due to the camber angle of the tyres. Hence the camber angle of the tractor rear tyre was at a value which created a gap between the road and the side of the tyre. Also, the road camber is made in such a way that it promotes more road-tyre contact at the inner end of the tyre compared to the outer end.

Due to the variations being observed, it was necessary to determine the significance of the variations observed in **Figure 4**. As a result, an analysis of variance at the 95% confidence interval (95% CI ANOVA test) was performed.

The first factors that were tested for any significant difference were position of the lug (outer lug of left tyre, outer lug of right tyre, inner lug of left tyre and inner lug of right tyre) and the points on the lug (side of lug, middle of lug and inner end of lug). The results of the analysis presented in **Table 3**, shows that there is no significant difference between the mean wear for the position on the lug where wear was measured since the P-value was greater than 0.05 (0.25 > 0.05). On the other hand, there was significant difference between the wear measured from the points on the lug ($3.91 \times 10^{-8} < 0.05$).

The deductions from the ANOVA test conducted with the data showed there was no difference between the wear measured from each lug but there was some difference in the data obtained from the points on each lug. The later can also be due to the fact that there was no wear observed at the side of the lug during each test.

In light of the preceding explanations, another ANOVA test was performed to determine if the position of the tyre (left tyre and right tyre) and the position of the lug (outer lug and inner lug) on the tyre affects the wear measured. The result of the analysis presented in **Table 4** showed that the P-values for both tests were greater than 0.05 (0.29 > 0.05 and 0.15 > 0.05 respectively).

This confirmed the observation that no significant difference existed between the mean wear measured for each tyre and each lug on the tyre at the 95% confidence interval. Furthermore, for highway use of the tractor rear tyre, there is a difference between the wear each point on a lug undergoes whiles there is no significant difference between the wear values obtained from each lug on the tyre and the position of the tyre (whether the left tyre or right tyre).

Conclusions

The provision of information on the wear of the agricultural wheel tractor rear tyre when it is being used for highway travel was the paramount aim of this study. Also, the wear value from this study was compared with an earlier study by Dorvlo et al., (2014).

On the rate of wear associated with the tractor rear tyre use for highway travel, the rear tyre wear rate found was $10.65 \pm 1.07 \times 10^{-4}$ mm/km. For this reason, the rear tyre is capable of travelling for 853.24 km with every millimeter of the rear tyre lug's height used. Also due to the wear distribution pattern shown, the middle portion of each tyre wears more than the side of the tyre where no wear measurements were recorded during this study.

A comparison of the results from this study with the findings from the study by Dorvlo et al., (2014) showed that the wear values are higher when using the tractor rear tyre for highway travel compared to ploughing. Then again, a comparison with the wear values for truck tyres (Lupker et al., 2002) showed that the tractor rear tyres undergo more severe wear than truck tyres.

It is therefore proposed that the tractor should be used for more on-farm work (ploughing) than highway travel. Using the tractor for highway travel should be done only if it is very necessary, since the more highway travel the rear tyre is used for, the higher the reduction in the total lug height on the rear tyre. Consequently, highway use of the tractor rear tyre will come at a higher opportunity cost to the farm machinery owner. As such it should only be done when there are no alternative modes of highway travel for the farmer.

Table 4 Statistical analysis of data from each lug and tyre

Source of Variation	SS	df	MS	F	P-value	F crit
WR	1.23×10^{-6}	1	1.23×10^{-6}	4.00	0.29	161.45
WC	4.94×10^{-6}	1	4.94×10^{-6}	16.00	0.15	161.45
Error	3.09×10^{-7}	1	3.09×10^{-7}			
Total	6.48×10^{-6}	3				

WR = wear data for outer and inner lug of each tyre; WC = wear data for left and right tyre; SS = Sum of Squares; df = degree of freedom; MS = Mean Square; F = calculated F-test value; P-value = probability value; F crit = F-test value from Fisher's distribution table.

REFERENCES

Casady, W. W. 1997. Tractor Tire and Ballast Management. Retrieved August 22, 2012 from the University of Missouri Extension website: http://extension. missouri.edu/p/ G1235.

Dorvlo, S. Y., A. A. Mahama and E. A. Baryeh. 2014. Evaluation of on-farm rear tyre wear rate in Ghana. Journal of the Ghana Science Association, Vol. 15 (2): 119-128

Lupker, H. A., F. Montanaro, D. Donadio, E. Gelosa and M. A. Vis. 2002. Truck tyre wear assessment and prediction. 7th International Symposium on Heavy Vehicle Weights & Dimensions, Delft, The Netherlands.

Mahama, A. A., Y. Dasana, E. Mensah and J. M. Seidu. 2004. Maintenance of tractor in the Northern Region of Ghana. 2nd International Conference on Agricultural Engineering (Hunger without Frontiers), KNUST, Kumasi, Ghana, 36-44.

Wulfsohn, D. and T. R. Way. 2009. Part VII: Factors that Influence Tractive Performance of Wheels, Tracks, and Vehicles of Chapter 2: Traction Mechanics. In Advances in Soil Dynamics Volume 3 (ed. S. K. Upadhyaya, W. J. Chancellor, J. V. Perumpral, D. Wulfsohn, and T. R. Way), pp. 209-252. St. Joseph, Mich.: ASABE.

Yap, P. 1989. Truck tire types and road contact pressures. British Columbia, Kelowna.

■■

Development and Evaluation of a Walking Type Two-row Semi-automatic Transplanter for Vegetable Plug Seedlings

by

Luhua Han
Key Laboratory of Modern Agriculture Equipment and Technology, Ministry of Education, Jiangsu University, Zhenjiang, CHINA

Menghan Mo
High-tech Key Laboratory of Agricultural Equipment & Intelligentization of Jiangsu Province, Zhenjiang, CHINA

Francis Kumi*
Dept. of Agricultural Engineering, School of Agriculture, University of Cape Coast, Cape Coast, GHANA
*Corresponding author: francis.kumi@ucc.edu.gh

Yang Liu
Mechanical Equipment Research Institute, Xinjiang Academy of Agricultural and Reclamation Science, Shihezi, CHINA

Haorui Ma
High-tech Key Laboratory of Agricultural Equipment & Intelligentization of Jiangsu Province, Zhenjiang, CHINA

Hanping Mao
Key Laboratory of Modern Agriculture Equipment and Technology, Ministry of Education, Jiangsu University, Zhenjiang, CHINA

Abstract

Seedling transplanting mechanization is key to overall success in vegetable production. Thus, in this study, a walking type 2-row semi-automatic vegetable transplanter was designed and evaluated in the field. The transplanter allows for manual feeding of the seedlings and their subsequent planting by the machine. The machine was designed to be attached to a walking tractor which had a height and spacing adjuster. The transplanting working units were modular in design consisting of distributors, five-bar planting mechanisms, inclined soil compacting wheels, flexible power transmission gearboxes, and seats. Each distributor was designed to have several cups that rotates and release seedlings to be fed into the planting mechanism, and the planting mechanism in turn move up and down to drill holes for placing seedlings in the soil. According to requirements of seedling precision transplanting, the motion dimension relation of the core parts was established. The dynamic analysis of the designed five-bar planting mechanisms was simulated with ADAMS software. The simulations indicated that the static trajectory of the duckbilled cup seemed like an oval shape of an egg, and the dynamic one was the trochoid. After completing the manufacturing prototype, its performance evaluation was conducted under actual production conditions. The performance tests showed that the qualified ratios of success in planting the two seedlings were all more than 90% at a working speed of 35 plants per row per minute. Also, the standard deviation of plant spacing was less than 3 cm, and more than 90% of seedlings were planted to the given depth of 7 cm. Compared to manual transplanting, this mechanical transplanting could obviously save costs and increase benefits.

Keywords: Vegetable, Transplanter, Five-bar planting mechanisms, Qualified ratio, Cost.

Introduction

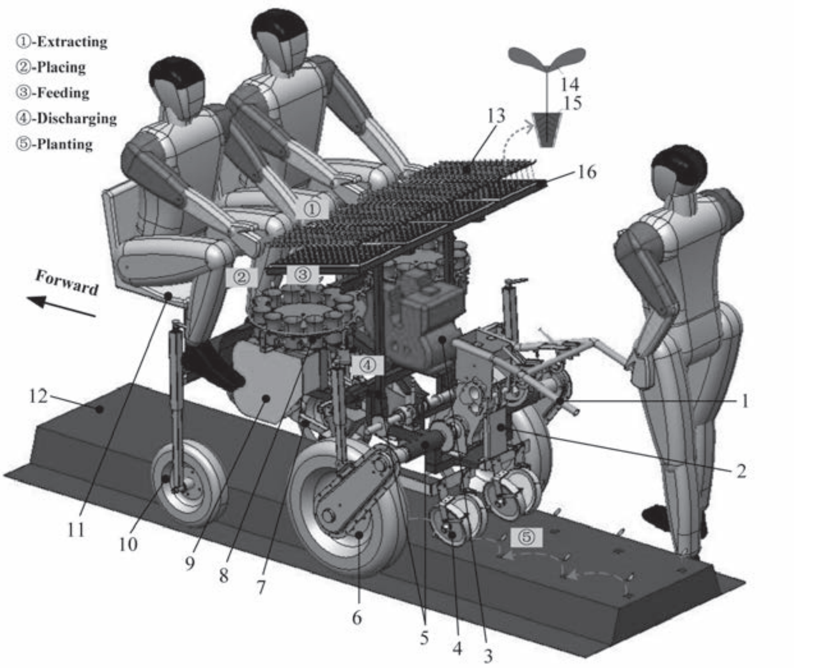
Vegetable production is essential in many countries (Kumar et al., 2008; Lim et al., 2017; Khadatkar et al., 2018; Han et al., 2019) and considered one of the important food items of daily diet without which any meal is incomplete. Globally, China is the leading producer of vegetables followed by India (Kumar et al., 2011; Mao et al., 2014). Vegetables have been second only to grain in crop farming, and the income from “vegetable basket” products has accounted for one third of farmers’ income in China (Wang et al., 2014). According to the China National Statistics Division, the total vegetable cultivation area in 2018 reached 20.44 million hectares with a yield of 700 million tons and the gross value of about 320 billion US dollars. With the increasing urbanization in many countries and quest for vegetables in the midst of COVID-19 pandemic, its consumer demand is expected to increase day-by-day. Therefore, it is of great significance to ensure the continuous and stable production of vegetables. Additionally, the general global trend has been the shortage of labor on the farm which calls for developing technologies aimed at reducing the labor-intensity while ensuring efficiency under increased cropping acreage.

In recent times, tray-grown transplants have largely replaced bare-root seedlings in tomato, pepper, and other vegetable production in many major growing areas (Mao et al., 2014; Han et al., 2018). Timely transplanting of these seedlings is very beneficial for their growth and yield (Du et al., 2018). It is a laborious and time-consuming field operation when performed manually. This traditional manual practice is to hold a bunch of seedlings/seedling tray in one hand, and separate seedlings by the other hand and press down the roots in the soil with bare hands (Khadatkar et al., 2018). According to statistics, the labor requirement in manual transplanting of vegetable seedlings varies from 180 to 420 man-hour ha^{-1} (Khadatkar et al., 2018). Thus, in major vegetable growing areas, efforts are being made to promote "machine replacement" project with interest in mechanical transplanting (Kumar et al., 2008; Khadatkar et al., 2018; Cui et al., 2019). Therefore, the development of mechanization of seedling transplanting is now becoming a priority for the industrialization of vegetable production among small farm holdings (Han et al., 2015).

Over the years, vegetable transplanters have been introduced for use by farmers and they often fall under two categories: fully automatic transplanters and semi-automatic transplanters (Tsuga, 2000; Kumar et al., 2008; Khadatkar et al., 2018). The fully automatic type of vegetable transplanters uses robotics, where seedlings can be fed automatically by the pick-up mechanism and planted without too much manual intervention (Tsuga, 2000; Yang et al., 2020). These transplanters allow for high-speed operation and efficient labor-savings. However, the automatic transplanters are sometimes complicated and require a very high level of skill to operate (Parish, 2005) and are often expensive and beyond the purchasing power of smallholder farmers. The maintenance and use of these machines require those who are professionals. Consequently, the fully automatic transplanters are not widely used by vegetable planters and often seen being showcased at product exhibition fares. On the other hand, although semi-automatic transplanters have limited operating speed due to the need for manual feeding of seedlings, these transplanters are often patronized by resource poor farmers in developing countries due to the fact that they are cheaper in terms of ownership and operating costs. Moreover, since seedlings are manually picked and released into the cup in the feeder mechanism and the people doing so are in a position to select only the good ones to be placed into the planting mechanism.

In terms of technological advancement of the transplanting machinery, researchers have mainly focused on the design of planting mechanisms and their structural parameter optimization (Hu et al., 2013; Yu et al., 2015; He et al., 2016; Wang et al., 2017; Ji et al., 2018). With increase in the demand for improving the transplanting operation, different innovations and mechanisms have been introduced with various degrees of efficiencies and shortcomings. Bhambota et al. (2018) innovated a tractor operated semi-automatic two row vegetable transplanter by combining the technology of the ditch opener. Han et al. (2019) developed a simple and convenient semi-automatic electric chili pepper planter using a slider-crank module. These researches have made significant contribution to the development of the transplanting machines. However, most of the works done only aim at the technical aspects of the machine with very little attention paid to integrating it with field per-

Fig. 1 The overall structure and the operating principle of the vegetable transplanter



1) Operating handle; 2) Operating Gearbox; 3) Gasoline engine; 4) Soil compacting wheels; 5) Chassis frame; 6) Driving wheel; 7) Planting mechanism; 8) Distributor; 9) Power transmission gearbox; 10) Driven wheel; 11) Seat; 12) Soil ridge; 13) Plug seedling; 14) Seedling leaf; 15) Seedling root soil; 16) Tray holder.

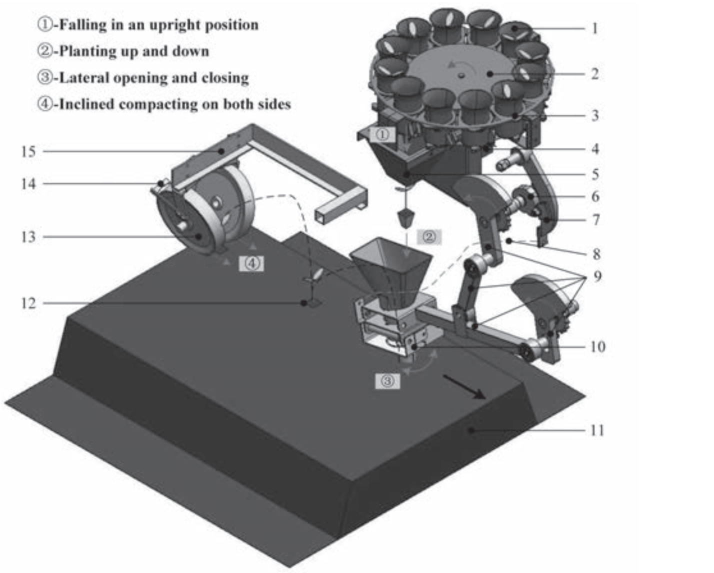
formance of the machine and its associated costs and comparing same to manual transplanting.

The objectives of this study were to deveop a walking type 2-row semi-automatic seedling transplanter and evaluate its field performance under actual production conditions. The cost analyses of seedling transplanting machine in comparison with manual method was also done.

Material and Methods

A walking type 2-row semi-automatic vegetable transplanter was designed in collaboration with Hualong Agricultural Equipment Co., Ltd., Shandong, China. **Figure 1** shows the drawing of the overall structure and the operating principles of the semi-automatic vegetable transplanter. The main frame of this machine was designed with a walking tractor consisting of two operating handles, an operating gearbox, a gasoline engine, a chassis frame, four wheels, and a tray holder. The height of the chassis frame and the spacing of the walking wheels can be adjusted as needed. The power of the gasoline engine is transferred to the operating gearbox through the belt attached to the pulleys, which is distributed to the walking wheels and the transplanting units. The transplanting working units were designed as a modular unit. Each transplanter unit consists of a distributor, a planting mechanism, soil compacting wheels, a power transmission gearbox, and a seat, which is mounted on the chassis frame in the detachable connection way. The whole machine can be configured for planting one row, two rows, and more rows by mounting the desired number of transplanting working modules onto a suitably sized chassis frame with the module positioned at the desired inter-row spacing. The distributor with a rotating cup type structure could supply seedlings in-step with the planting mechanism. When the planting mechanism moves up and down once, the distributor cups turn one. As the machine moves forward, the planting mechanism continuously plant the seedlings into the soil. Then the optional soil compacting wheels put soils around the seedlings when the soil ridge is not covered by the plastic mulch film.

Fig. 2 The three-dimensional structure of the transplanting working unit



1) Distributor cups; 2) Rotating discs; 3) Ring frame; 4) Power transmission gearbox; 5) Guiding tube; 6) Opening and closing cam; 7) Oscillating bar; 8) Pulling wire; 9) Five-bar planting mechanism; 10) Duckbilled cup; 11) Soil ridge; 12) Plug seedling; 13) Soil compacting wheel; 14) Scraping bar; 15) Connecting frame

The machine in use requires three persons: One person walks in the furrows and is required to guide and operate the machine, while two other persons sit on the seats and are tasked to remove the seedlings from the tray cells and place them into the machine for planting. The specific operation of seedling transplanting can be described as follows.

1. The nursery trays are placed on the tray holder. The machine parts begin working as it moves on unto the ridge.
2. As the planting arm gets close to the ridge, the operator places the seedlings upright into the rotating distributor cups.
3. The distributor cups rotate with the intention of transferring the seedlings into the planting mechanism at a predetermined interval.
4. The valve at the bottom of each cup opens up when it reaches the point of release. The planting mechanism gets lifted to receive the seedling and discharges it into the closed duckbilled cup.
5. Following a fixed working trajectory, the closed duckbilled cup of the planting mechanism starts to open up when it has penetrated into the soil up to the desired depth. The seedling is then planted in the soil. Finally, the duckbilled cup closes as the planting mechanism accepts the next seedling from the distributor cup as it comes out from the soil.

In the operation of the machine, the operators are made to sit above each transplanter module within the reach of the seedling trays. The distributor cups are designed to have flat bottom openings. As shown in **Figure 2**, the seedlings placed into the cups were then transported by rotation and discharged. The guiding tube with a certain degree of tapering was installed below the discharging point for setting the seedlings upright. Also, the guiding tube helps to guide the dropping of the seedlings from the cup to the planting arm (Liu et al., 2018). As a guiding principle, much consideration was given to the spacing of the cups on the distributor in order to achieve the needed plant spacing on the ridge. The upper part of the duckbilled cup was designed to have a square large bell-mouth shape for receiving seedlings into the bottom, and the lower part had a truncated cone with two opposite sides in duckbilled shape to penetrate the soil and drill a hole for dropping the seedlings. The cup driven by an opening and closing cam mechanism began laterally opening after creating furrow into the soil to a desired depth. As the cup comes out of the soil, it begins to close by the action of the high-strength spring. The seedlings are then released into the soil. Finally, a pair of inclined compacting wheels rolled on both sides of the planted seedlings to cover and compact the soil around the roots and ensure uprightness of the seedlings.

The planting mechanism used was a five-bar planting device with a duckbilled cup drilling hole up and down. It was made of a two degree of freedom mechanism with two power inputs. The different dimensions of each bar group can form the different working trajectories and postures of the duckbilled cup (Xu et al., 2018). **Figure 3** shows the mathematical model and boundary conditions of the five-bar planting mechanism. A rectangular coordinate system is established with the coordinate origin of point O, the horizontal direction of the X-axis and the vertical direction of the Y-axis. In order to create a reasonable working trajectory of point G at the bottom of the duckbill planter, a series of displacement relationships are strictly defined.

Obviously, the displacement of point D and point B can be described as follows.

$$\text{Point D: } \begin{cases} X_D = X_O + l_5\cos\theta_5 \\ Y_D = Y_O + l_5\sin\theta_5 \end{cases} \quad (1)$$

$$\text{Point B: } \begin{cases} X_B = X_A + l_2\cos\theta_2 \\ Y_B = Y_A + l_2\sin\theta_2 \end{cases} \quad (2)$$

Where, (X_D, Y_D), (X_O, Y_O), (X_A, Y_A) and (X_B, Y_B) are the coordinate values of point D, O, A and B, respectively; l_5 and l_2 are the lengths of the driving link 5 (from point O to point D) and the driving link 2 (from point A to point B), respectively; θ_5 and θ_2 are the angles of positive X-axis intersected with the driving link 5 (from point O to point D) and the driving link 2 (from point A to point B), respectively.

According to the theory of mechanisms, the closed-loop vector equation is expressed as follows,

$$\overrightarrow{OA} + \overrightarrow{AB} + \overrightarrow{BC} = \overrightarrow{OD} + \overrightarrow{DC} \quad (3)$$

After the coordinate projection transformation, the vector equation of equation 3 is described with the same coordinate values of point C as follows,

$$\begin{cases} l_1\cos\theta_1 + l_2\cos\theta_2 + l_{10}\cos\theta' + l_5\cos\theta_5 + l_4\cos\theta_4 \\ l_1\sin\theta_1 + l_2\sin\theta_2 + l_{10}\sin\theta' + l_5\sin\theta_5 + l_4\sin\theta_4 \end{cases} \quad (4)$$

Where, l_1, l_2, l_{10}, l_5 and l_4 are the lengths of the frame 1 (from point O to point A), the driving link 2 (from point A to point B), the connecting link 10 (from point B to point C), the driving link 5 (from point O to point D) and the connecting link 4 (from point D to point C), respectively; θ_1, θ_2, θ_{10}, θ_5 and θ_4 are the angles of positive X-axis intersected with the frame 1 (from point O to point A), the driving link 2 (from point A to point B), the connecting link 10 (from point B to point C), the lengths of the driving link 5 (from point O to point D) and the connecting link 4 (from point D to point C), respectively.

Here, a short connecting link 7 (from point C to point H) was set to be perpendicular to a long connecting link 3 (from point B to point H). According to the geometric coordinate relations, a set of rectangular equations are easily obtained as follows.

$$\begin{cases} l_{10} = \sqrt{l_7^2 + l_3^2} \\ \theta' = \theta_3 - \arctan l_7/l_3 \end{cases} \quad (5)$$

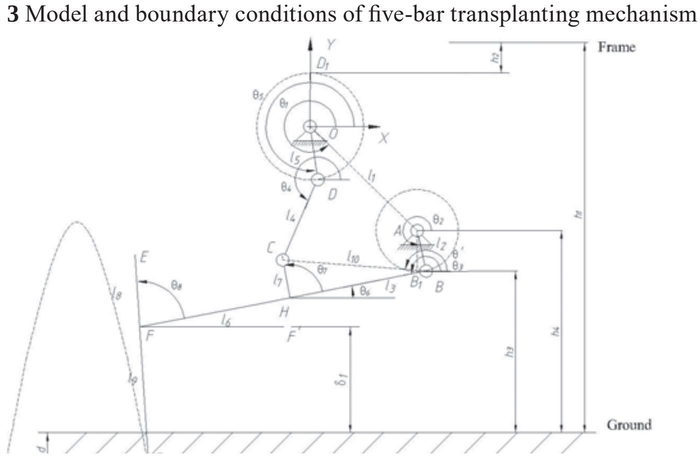
Where, l_{10}, l_7 and l_3 are the lengths of the connecting link 10 (from point B to point C), the short connecting link 7 (from point C to point H) and the long connecting link 3 (from point B to point H), respectively; θ_{10}, θ_7 and θ_3 are the angles of positive X-axis intersected with the connecting link 10 (from point B to point C), the short connecting link 7 (from point C to point H) and the long connecting link 3 (from point B to point H), respectively.

Here, Eq. 5 was substituted into Eq. 4. It can be expressed in a short form as follows.

$$\begin{cases} l_1\cos\theta_1 + l_2\cos\theta_2 + \sqrt{l_7^2 + l_3^2}\cos(\theta_3 - \arctan l_7/l_3) = l_5\cos\theta_5 + l_4\cos\theta_4 \\ l_1\sin\theta_1 + l_2\sin\theta_2 + \sqrt{l_7^2 + l_3^2}\sin(\theta_3 - \arctan l_7/l_3) = l_5\sin\theta_5 + l_4\sin\theta_4 \end{cases} \quad (6)$$

Where, l_1, l_2, l_7, l_3, l_5 and l_4 are the lengths of the frame 1 (from point O to point A), the driving link 2 (from

Fig. 3 Model and boundary conditions of five-bar transplanting mechanism



point A to point B), the short connecting link 7 (from point C to point H), the long connecting link 3 (from point B to point H), the driving link 5 (from point O to point D) and the connecting link 4 (from point D to point C), respectively; θ_1, θ_2, θ_3, θ_5 and θ_4 are the angles of positive X-axis intersected with the frame 1 (from point O to point A), the driving link 2 (from point A to point B), the connecting link 3 (from point B to point H), the lengths of the driving link 5 (from point O to point D) and the connecting link 4 (from point D to point C), respectively.

To simplify the above equation, the following value was set by the mathematical transformations and square operations.

$$\begin{cases} a = l_1\cos\theta_1 + l_2\cos\theta_2 - l_5\cos\theta_5 \\ b = l_1\sin\theta_1 + l_2\sin\theta_2 - l_5\sin\theta_5 \\ c = (a_2 + b_2 + l_4^2 - l_7^2 - l_3^2) / 2l_4 \end{cases} \quad (7)$$

Where a, b and c are the set values, respectively; l_1, l_2, l_5, l_4, l_7 and l_3 are the lengths of the frame 1 (from point O to point A), the driving link 2 (from point A to point B), the driving link 5 (from point O to point D), the connecting link 4 (from point D to point C), the short connecting link 7 (from point C to point H), and the long connecting link 3 (from point B to point H), respectively; θ_1, θ_2 and θ_5 are the angles of positive X-axis intersected with the frame 1 (from point O to point A), the driving link 2 (from point A to point B) and the lengths of the driving link 5 (from point O to point D), respectively.

According to the simplified set values of a, b and c, the angles of positive X-axis intersected with the connecting link 4 can be calculated as follows.

$$\theta_4 = \arcsin = c / (\sqrt{a_2 + b_2}) - \arctan a/b \quad (8)$$

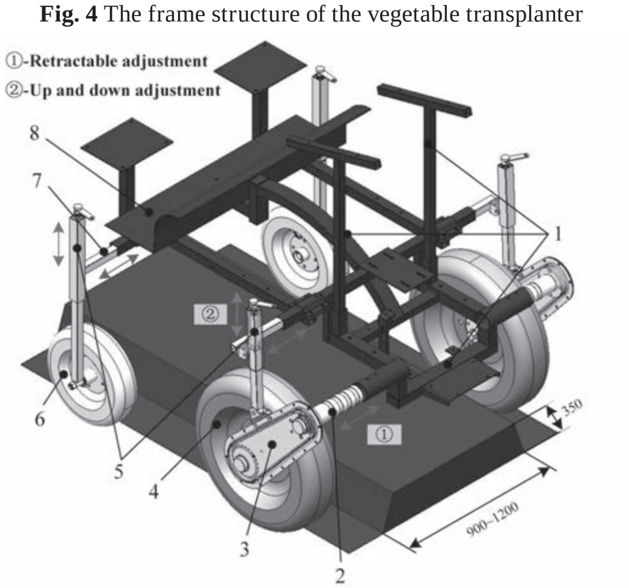
Where θ_4 is the angle of positive X-axis intersected with the connecting link 4 (from point D to point C); a, b and c are the set values, respectively.

Here, Eq. 8 was substituted into Eq. 4. The angles of positive X-axis intersected with the connecting link 3 can be expressed in a short form as follows.

$$\theta_3 = \arccos (l_4\cos\theta_4 - a) / (\sqrt{l_7^2 + l_3^2}) + \arctan l_7/l_3 \quad (9)$$

Where, θ_3 and θ_4 are the angles of positive X-axis intersected with the long connecting link 3 (from point B to point H) and the connecting link 4 (from point D to point C), respectively; l_7 and l_3 are the lengths of the short connecting link 7 (from point C to point H) and the long connecting link 3 (from point B to point H), respectively; a is the set values.

Fig. 4 The frame structure of the vegetable transplanter



1) Square profile steels; 2) Telescopic shaft; 3) Chain transmission box; 4) Driving wheel; 5) Spiral screw; 6) Driven wheel; 7) Adjustable square tubes; 8) Pedal

Obviously, the displacement of point F and point G can be described as follows.

Point F:

$$\begin{cases} X_F = X_B + (l_3 + l_6)\cos\theta_3 \\ Y_F = Y_B + (l_3 + l_6)\sin\theta_3 \end{cases} \quad (9)$$

Point G:

$$\begin{cases} X_G = X_F + l_9\cos(2\pi - \theta_3 - \theta_8) \\ Y_G = Y_F + l_9\sin(2\pi - \theta_3 - \theta_8) \end{cases} \quad (10)$$

Where, (X_F, Y_F), (X_G, Y_G) and (X_B, Y_B) are the coordinate values of point F, G and B, respectively; l_3, l_6 and l_9 are the lengths of the long connecting link 3 (from point B to point H), the long connecting link 6 (from point H to point F) and the duckbilled cup (from point F to point G), respectively; θ_3 and θ_8 are the angles of positive X-axis intersected with the connecting link 3 (from point B to point H) and the duckbilled cup in assembly (from point F to point G), respectively.

Based on the above analysis, the displacement of point G on the duckbill cup mainly depends on the basic dimensions and initial assembly angles of the five-bar planting mechanism. Also, the motion of the duckbill cup can be affected by the driving link 5 (from point O to point D) and the driving link 2 (from point A to point B). Further, the velocity and acceleration equations of each point on the duckbill cup can be obtained by solving the first and second derivatives of Eq. 11.

Based on the structural and spatial layout of the vegetable transplanter, these can give the basic dimensions of the linkage group. In order to avoid the interference between the frame, the ridge surface and the five-bar planting mechanism, the highest point D_1 that the driving link 5 (from point O to point D) can reach should keep a certain distance of h_2, and the lowest point B_1 that the driving link 2 (from point A to point B) can reach should be higher than a certain distance of h_3. So, the height of h_1 between the frame and the ground should meet the following requirement.

$$h_1 = h_2 + l_1\sin\theta_1 + l_2 + l_5 + h_3 \quad (12)$$

Where, h_1, h_2 and h_5 are the allowable height of the overall frame, the spacing distance of the driving link 2 (from point A to point B) and that of the driving link 5 (from point O to point D), respectively; l_1, l_2 and l_5 are the lengths of the frame 1 (from point O to point A), the driving link 2 (from point A to point B) and the driving link 5 (from point O to point D), respectively; θ_1 is the angles of positive X-axis intersected with the frame 1 (from point O to point A).

In the design, the allowable height of the frame was given as 1000 mm. Meanwhile, the spacing distance between the driving link 5 and the frame was greater than 50 mm, and the allowable height of the driving link 2 against the ground was greater than 500 mm. So, the basic dimensions of some driving links can be obtained as follows.

$$l_1\sin\theta_1 + l_2 + l_5 \le 450 \text{ mm} \quad (13)$$

Where, l_1, l_2 and l_5 are the lengths of the frame 1 (from point O to point A), the driving link 2 (from point A to point B) and the driving link 5 (from point O to point D), respectively.

In order to make the five-bar planting mechanism flexible with good performance, the basic dimensions of some driving and connecting links can be obtained as follows.

$$\begin{cases} h_4 > \delta_1 + l_2 \\ l_4 < l_3 \le l_6 < l_{10} = \sqrt{l_7^2 + l_3^2} \\ l_3 + l_6 < 500 \text{ mm} \end{cases} \quad (14)$$

Where, h_4 is the allowable mounting height of the driving link 2 (from point A to point B); l_2, l_3, l_4, l_6 and l_{10} are the lengths of the driving link 2 (from point A to point B), the long connecting link 3 (from point B to point H), the connecting link 4 (from point D to point C), the long connecting link 6 (from point H to point F) and the connecting link 10 (from point B to point C), respectively.

Based on the existence conditions of the double driving links, the five-bar planting mechanism was designed to meet the following conditions.

$$\begin{cases} l_4 + l_{10} \ge l_1 + l_2 + l_5 \\ |l_4 - l_{10}| \ge l_1 - (l_2 + l_5) \end{cases} \quad (15)$$

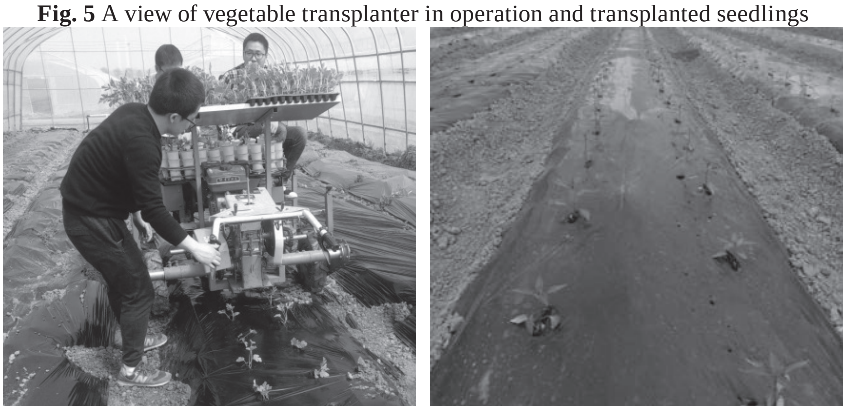
Where, l_1, l_2, l_4, l_5 and l_{10} are the lengths of the frame 1 (from point O to point A), the driving link 2 (from point A to point B), the connecting link 4 (from point D to point C), the driving link 5 (from point O to point D) and the connecting link 10 (from point B to point C), respectively.

In design, the duckbilled cup drilling holes up and down for transplanting should adapt to a variety of vegetable seedlings such as tomatoes, peppers and others. This requires that the length of the duckbilled cup (from point F to point G) is greater than the sizes of those vegetable seedlings. Based on the above analysis, it is finally determined that the bar length parameters of each member of the five-bar planting mechanism and the correspond initial angles.

On basis of the working-conditions constraint, 3D solid model of the five-bar transplanting working unit was designed using SolidWorks 2018 software (Dassault Systems S.A©, Concord, Massachusetts, USA). And the kinematic analysis of mechanism was simulated using Adams software (Mechanical Dynamics Inc.©, Ann Arbor, Mich., USA), which was to analyze the trajectory, velocity and acceleration of the end point on the duckbill cup. The corresponding mass and inertia data were created in the simulation and its material (steel) was specified. Variable kinematic joints were also added to the CAD geometry data of the five-bar transplanting mechanism for constraint modeling, and force modeling was conducted to apply interaction units among parts. Finally, it was set at a complete revolution of the driving link with a velocity of 40 rpm in the clockwise direction, a forward speed of 0.3 m/s and the simulation step was 200 steps/s.

Figure 5 shows the frame structure of the vegetable transplanter. The main frame of this machine was welded from the lightweight square profile steels with high strength. The driving wheels were connected to the operating gearbox by the telescopic shafts, and hinged to the main frame by the spiral screws. The driven wheels were also connected to the main frame by the spiral screws and the locked square tubes. The lifting height and walking width of the whole transplanting system could be flexibly adjusted to meet the planting requirements of different ridges. The suitable ridge size range was 900-1200 mm in width and 0-350 mm in height. The chain drive structure was used on the driving wheel, which may simplify the transmission structure and improve the work efficiency. With reference to the structure of the walking tractor, it was built with an engine connected to the power transmission unit having a gear box, clutches, brakes, turns and other corresponding operating

Fig. 5 A view of vegetable transplanter in operation and transplanted seedlings



handles. Finally, a prototype of the walking type 2-row semi-automatic vegetable transplanter was developed. The brief specifications of the machine are given in **Table 1**.

Preliminary tests were carried out to examine its functional requirements. In the first trial, the driving and maneuverability of the machine was assessed and found to be satisfactory. The left or right brakes were locked and the machine could turn around in place. When the machine goes straight along the standard ridge, it may travel a distance of about 10 m without human intervention. This maneuverability lessens the burden on the driver. Further tests were carried out to assess the placement and planting of the seedlings. When the operators extracted 30-40 plants per minute, they could easily pull out the seedlings from the tray cells and distribute the seedlings into the cups. Thus, this was the recommended range for the feeding rate of the seedlings. With an extraction rate of more than 40 plants per minute, the operators were nervous and kept their eyes on the rotating seedling cups. Such intense operations made the operators very tired, and they were unable to work for a long time. It was recommended to set the appropriate operating frequency according to the operators' work duration.

In April, 2021, field evaluation trials were conducted in a greenhouse base, Huai'an National Agricultural Science and Technology Park, Jiangsu, China. The soil in this area belongs to the sand clay loam textural class. Before transplanting, the soil was mechanically ploughed, harrowed and ridged on the basis of cultural practice for local vegetable production. The transplanting objects were tomato and pepper seedlings. These seedlings were cultivated in the 72-cell polystyrene trays (Truncated pyramid shape tray cell: 6 × 12 arrangement, top and bottom diameter 40 mm and 15 mm respectively, and height 45 mm) in a seedling base at Jiangsu Academy of Agricultural Sciences, Nanjing, China. They had sturdy plants and strong root soils, and some growth characteristics as presented in **Table 2**. The seedlings were irrigated a day before transplanting, and the moisture contents of their root soils were found to be within the range of 55-60% (Mao et al., 2014).

Table 1 Brief specifications of the vegetable transplanter

Parameters	Specifications
Type of the machine and size	Walking type, semi-automatic, 2-row
Weight of the machine (kg)	340 (Without operators and seedling trays)
Power required, hp	5.5 hp
Seedling type	Plugged seedlings grown in a cell tray
Type of the clutch	Belt tensioning
Type of the distributor	Distribution system with 12 flat bottom opening cups
Type of the planting mechanism	Duckbilled cup type planting mechanism
Working speed (km/h)	0.8-1.5
Row spacing (cm)	30-50
Range of plant spacing (cm)	25-50
Range of depth spacing (cm)	6-12
Working capacity (ha/h)	0.1-0.13
Type of bed maker	Ridge type or flat tilled land, mulch film or bare

Table 2 Characteristics of seedlings used for the field evaluation

Seedling	Seedling age, days	No. of Leaves	*Plant height, mm	*Leaf length, mm	*Leaf width, mm
Tomato	35	5-6	131.65 ±5.28	39.73 ±4.67	28.09 ±4.33
Pepper	46	7-9	182.17 ±6.41	34.19 ±5.75	24.62 ±4.17

*Data are mean ± SD.

The production pattern of transplanting was of planting seedlings along two rows on one ridge, with a mulching plastic film (**Figure 6**). The planting spacing distance was set at 350 mm and 400 mm for tomato seedlings and pepper seedlings, respectively. The ridge dimensions were 1000 mm wide and 200 mm high. The planting depth of seedlings was set at 7 cm below the soil. The machine operation parameters were adjusted to adapt to this ridge conditions. The transplanting rates were set at 35 plants per row per minute that the operators can feed seedlings easily without getting tired. Each test was conducted in a standard vegetable greenhouse with 100 m length, 8 m width and 4 m height. The layout provided a head land of 3 m to 5 m for turning the machine.

Field performance of the developed transplanter was evaluated in terms of a qualified ratio of success in planting seedlings, a coefficient of variation of plant spacing, and a qualified ratio of planting depth. The qualified ratio of success in planting seedlings represents how successfully the machine performs transplanting of seedlings without plant missing, multiple planting, plant inclination and plant damage. If there was no seedling at the expected plant spacing position, it was taken as a miss. On the other hand, if there was more than one seedlings at the expected position, it was taken as multiple planting. Plant inclination with the horizontal in a row, was measured by using a protractor with a flat base attached to it. When the inclination was less than 30 degrees, it was considered as plant inclination failure. In all, the qualified ratios of success in planting seedlings were investigated. The corresponding transplanting results were recorded.

According to the industry standard of the transplanting machine (JB/T 10291-2013), a coefficient of variation of plant spacing (CV) was determined using the following relation:

$$\begin{cases} CV = (S_X / \overline{X}) \times 100\% \\ S_X = \sqrt{\dfrac{1}{n-1} \sum_{i=1}^{n} (X_i - \overline{X})^2} \\ \overline{X} = \dfrac{\sum_{i=1}^{n} X_i}{n} \end{cases} \quad (21)$$

Where, S_X = the standard deviation of plant spacing, cm; $\overline{X}$ = the average value of plant spacing, cm; n = the number of seedlings tested; X_i is the qualified value of plant spacing, cm.

A qualified ratio of planting depth (Q_{PD}) is determined as follows:

$$Q_{PD} = (N_{PD} / N) \times 100\% \quad (22)$$

Where, N_{PD} = the number of seedlings planted at the set depth; N = the total number of planting seedlings.

In testing, the qualified ratios of success in planting seedlings were investigated for all the transplanted seedlings in one row. Planting accuracy for 160 seedlings was randomly selected for the data analyses of the plant spacing and the planting depth. All datasets were repeated three times for each of tomato and pepper seedlings.

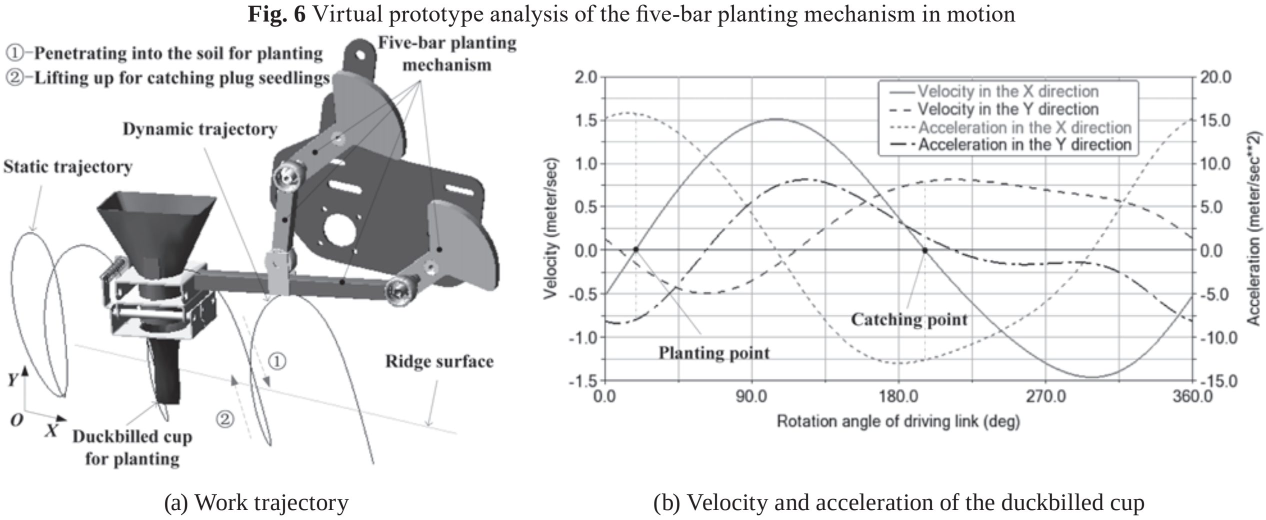
Results and Discussion

The advantages of containerized transplants from a vegetable production perspective have been widely recognized (Shaw 1993; Lim et al., 2017; Han et al., 2019). Based on vegetable production practice, a simple walking type 2-row semi-automatic transplanter was developed for vegetable plug seedlings. Its chassis system was designed to suit a typical walking tractor. Considering the variety of vegetable transplanting, this chassis was made to be structurally flexible and adjustable. As the core of machine, the transplanting working unit was modular in design and adjustable when the need arises. Even without automated plant handling, it is possible to improve the efficiency of mechanical transplanting by using the distributor cups to allow multiple loading locations in which the operator can place seedlings. Certainly, transplanting rates of seedlings vary with respect to work duration and skill of the operator. The planting mechanism was designed with a five-bar duckbilled cup type device, which can drill holes up and down for seedling transplanting.

As shown in **Figure 6a**, the static and dynamic trajectory of the five-bar planting mechanism in motion were recorded in the resulting data. Its static trajectory of the duckbilled cup seems like an oval shape of an egg, and the dynamic one is the trochoid depending on the horizontal moving speed of the whole machine and the rotation speed of the drive link. On the whole, the duckbilled cup driven by the five-bar planting mechanism can penetrate into the soil for drilling holes. Then, the duckbilled cup was lifted up with the discharge of plug seedlings into the soil. As the duckbilled cup moved to the top, it may catch another seedling. As shown in **Figure 4b**, the peak velocity, from the horizontal and the vertical, were estimated to be 1.51 m/s and 0.81 m/s, and the peak acceleration were and 15.82 m/s^2 and 8.13 m/s^2, respectively. The peak acceleration of this planting mechanism was far less than the planting mechanism with planetary gears of transplanting machine (Hu et al., 2013). Both the kinematic horizontal velocity at the planting point and at the catching point were 0 m/s, which was benefit for stable planting operations. It resulted in the minimum inertia to keep the duckbilled cup acting on the seedlings. The rotational angle of the driving link to move the duckbilled cup from the planting point to the catching point was about 178° in the clockwise direction, and that one from the catching point to the planting point was about 182°. Thereby, the time ratio of the working phases was almost equal to the non-working. This five-bar planting mechanism can move the duckbilled cup slightly slowly to penetrate into the soil for planting seedlings, and return slightly quickly to the catching point for the next transplanting.

Additionally, the result of the field evaluation was is presented. The planting quality parameters of the of tomato and pepper seedlings

Fig. 6 Virtual prototype analysis of the five-bar planting mechanism in motion



(a) Work trajectory

(b) Velocity and acceleration of the duckbilled cup is shown in **Table 3**. Several tests showed that the qualified ratios of success in planting seedlings were more than 90%, which well met most industry standard requirements. On the whole, the pepper seedlings were easier to transplant mechanically than the tomato seedlings. The average qualified ratios were 94.55% and 93.07% for 46-day pepper seedlings and 35-day tomato seedlings, respectively. The reason may be that the stems of pepper seedlings were relatively straight, which was easy to pull seedlings for planting. For tomato seedlings, 37 cases of plant missing, plant doubling and plant inclination were recorded and this is regarded to be more than half of the transplanting failures. During transplanting time, it was realized that the tomato seedlings had a wider leaf spread and as a result, tomato seedlings interfered with the mechanism as it passes through the distributor cups and the guiding tubes. To some extent, the root soils of some seedlings were not well developed and due to this it was observed that after manual placement into the distributor cup and discharging through the duckbilled cup, the plug seedlings end-up being bare-root seedlings (Liu et al., 2018). This fact confirms again that those uniform, short and sturdy seedlings with root system well developed are more suitable for mechanized transplanting (Shaw, 1993; Han et al., 2015; Kumi et al., 2016).

As the soil in the greenhouses had a good reflux, the planting mechanism could place the seedlings in the field and pack soil around each of them. As a result, cases of seedlings covered or exposed rarely occurred. In the transplanting work, it was occasionally found that it is sometimes difficult to quickly extract and place the seedlings from the cells as reported by Yang et al. (1991). Hence it was noticed that if the pre-extracted seedlings had been manually pulled out of the cell before the actual operation and then carefully returned to the cells, the operators are able to easily extract and place seedlings into the cups one at a time during the actual operation.

Table 4 shows that the planting accuracy of this transplanter. On the whole, the seedlings were efficiently transferred to the five-bar planting mechanism and subsequently placing them one by one in the field at designated intervals and depths. The average coefficients of variation of plant spacing were 6.84% and 5.77% for pepper seedlings and tomato seedlings, respectively. These were far below the industry standard requirement of 15%. They had a standard deviation of no more than 3 cm. The planting duckbilled cup was used in laterally opening and closing way, which was not easy to push the seedlings over. The transplanter could basically keep a relatively fixed interval to drill a hole and then plant a seedling. The results of random sampling showed that the depths of mechanized seedling planting were consistent, which were more than 90% of the industry standard requirements. A row of seedlings was transplanted evenly as far as the eye could see. Because the machine had no profiling control mechanism to sense the ground conditions, the five-bar planting mechanism by itself could not adapt to the change of ridge shape. Therefore, some of the seedlings were shallowly planted on ridges. There was the potential to lodge to varying degrees in further growth (Yamamoto et al., 2016). Transplanting of plug-grown seedlings at reasonably increased depth may address the problem of shallow planting. If the ridging surface and the furrow were kept relatively flat, the machine can also transplant seedlings at the required depth. This requires experience in the development and use of a set of operating specifications

Table 3 Results of planting accuracy of the transplanter

Particulars*	Tomato			Pepper		
	Row 1	Row 2	Row 3	Row 1	Row 2	Row 3
N_{PR}	255	255	255	220	220	220
N_{PM}	6	4	3	2	2	3
N_{PD}	3	5	4	2	2	3
N_{PI}	5	4	3	3	3	2
N'_{PD}	2	4	5	4	2	1
N_O	2	2	1	2	3	2
Q, %	92.94	92.55	93.73	94.09	94.55	95.00
Average, %		93.07			94.55	

*N_{PR}, Numbers of plant required; N_{PM}, Numbers of plant missing; N_{PD}, Numbers of plant doubling; N_{PI}, Numbers of plant inclination; N'_{PD}, Numbers of plant damage; N_O, Numbers of others (seedlings covered or exposed); Q, Qualified percent of success in planting seedlings.

Table 4 Results of planting accuracy of the transplanter

Particulars		Tomato			Pepper		
		Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
Plant spacing[1]	$\overline{X}$, cm	34.78	35.06	34.65	39.85	39.27	40.18
	S_X, cm	2.14	2.65	2.36	2.28	2.17	2.44
	CV, %	6.15	7.56	6.81	5.72	5.53	6.07
	Av., %		6.84			5.77	
Planting depth[2]	N	160	160	160	160	160	160
	N_{PD}	145	147	146	148	146	151
	Q_{PD}, %	90.63	91.88	91.25	92.50	91.25	94.38
	Av., %		91.25			92.71	

[1]$\overline{X}$, average value of plant spacing; S_X, standard deviation of plant spacing; CV, coefficient of variation of plant spacing; [2]N, total number of planting seedlings; N_{PD}, qualified number of planting depth; Q_{PD}, qualified percent of planting depth.

from plowing to transplanting. In the future, the interaction automatic planting depth control unit and ridge-following control unit could be further studied and incorporated to improve the adaptability of the machine (Tsuga, 2000).

Based on local labour and material costs, the economic benefits of mechanical and manual transplanting were analyzed. It was assumed that the time available for mechanical transplanting work was 8 h per day, and the working capacity was approximately 0.1 ha/h while the operators can feed seedlings easily. The difference between two planting methods was calculated at the cost per hectare regardless of productivity.

As shown in **Table 5**, the costs of mechanical transplanting mainly consisted of three operators' fees, machine rental fees and seedling fees. Each operator earns about $30 a day. The cost of machine includes repair and maintenance, insurance, lubrication and fuel. Seedling fees were calculated according to the number of tray per hectare and the price of seedling per tray. The total cost of mechanical transplanting per hectare was calculated as $112.5, $50, and $846 for operators' fees, machine fees, and seedling fees, respectively.

The costs of manual transplanting mainly included purchasing the seedling (seedling fees) and labor which involved transporting seedlings, digging holes for planting, packing soil around each seedlings, and others. The manual transplanting was not uniform, which increased the quantity of seedlings used. Manual transplanting of each tray of seedlings costed $0.5, which was calculated in addition to the operator's daily salary and transplanting workload. For manual transplanting of seedlings, the sum of costs per hectare was up to $1351.5 by the calculation. Thus, manual transplanting had $343 more than the total cost of mechanical transplanting on the acreage of one hectare. It could therefore be concluded that mechanical transplanting could save more money than manual transplanting. As one increases the area of planting, the economic benefit would largely increase.

As can be seen from the production application, the transplanter could feed seedlings, transfer them, and plant them in the field at designated intervals, depths, and pack soil around each one of them (Bhanbota, et al., 2018; Du et al. 2018; Han et al., 2019). This transplanting operation is flexible and adjustable. The traditional manual transplanting is labor intensive and associated with high level of drudgery as the operation is done in a bending and squatting posture (Khadatkar et al., 2018). Also, it is difficult to ensure the quality and accuracy of seedling transplanting . Due to long duration of being in a squatting posture, it may cause muscular fatigue with its associated long-term health implications.

Generally, semi-automatic vegetable transplanters are simple in structure and low in price suitable for uptake by smallholder and resource poor farmers in developing countries. If more distributor cups are in place and the rotation mechanism made to synchronize with the planting mechanism, it could ensure high transplanting efficiency. Growth observation showed that the rejuvenation period after mechanical transplanting was about 7 days, while the rejuvenation period of manual transplanting was twice as long. This semi-automatic transplanting technology could be introduced and popularized for use by smallholder farmers in developing countries.

Conclusions

As conclusions, a walking type 2-row semi-automatic transplanter for plug seedlings was developed. The transplanter allows for manual feeding seedlings and subsequent planting mechanically. In practice, this machine enables continuous transplanting work on 2 ridges simultaneously at a planting speed of 35 plants per row per minute that the operators can feed seedlings easily. Several tests showed that the qualified ratios of success in planting seedlings and planting depth were more than 90%. Compared to manual transplanting, mechanical transplanting using this machine could save costs. Growth observation after transplanting showed that the rejuvenation period after mechanical transplanting was shorter than manual transplanting. In future the stability of the machine under different field conditions could be looked into.

Ackonwledgements

This work was supported by a grant from the National Natural Science Foundation of China (No. 51975258), the Priority Academic Program Development of Jiangsu Higher Education Institutions (No. PAPD-2018-87), the Jiangsu Demonstration Project of Modern Agricultural Machinery Equipment and Technology (No. NJ2019-19), and the Open Fund of High-

Table 5 Cost analysis of mechanical and manual transplanting

Particulars		No.	Unit cost, U.S. dollar	Total cost per hectare, U.S. dollar	Sum, U.S. dollar
Mechanical transplanting[1]	Operator	3	30	112.5	1,008.5
	Machine	1	40	50	
	Seedlings[2]	705	1.2	846	
Manual transplanting	Seedlings[2]	795	1.2	954	1,351.5
	Operatiing[3]	795	0.5	397.5	

[1]Production efficiency (8-hour work day): 0.8 hectares per day; [2]Required tray seedlings per hectare; [3]Operating cost (carrying seedlings, digging holes for planting, packing soil around each seedlings, and so on)

tech Key Laboratory of Agricultural Equipment and Intelligentization of Jiangsu Province (No. JNZ201910).

REFERENCES

Bhambota, S., A. K. Dixit, G. S. Manes, A. S. Dhatt, S. K. Singh and Arshdeep Singh. 2018. Field evaluation of a semi-automatic vegetable transplanter for major vegetable crops. Indian J. Agric. Sci., 88(11): 107-111.

Cui, Z., C. Guan, Y. Yang, Q. Gao, Y. Chen and T. Xiao. 2019. Research status of vegetable mechanized transplanting technology and equipment. J. Chinese Agric. Mech., 41(3): 85-92.

Du, S., Yu J., Wang W., 2018. Determining the minimal mulch film damage caused by the up-film transplanter. Adv. Mech. Eng., 10(3): 1-13. https://doi.org/10.1177/1687814018766777

Han, C., C. Oh and G. Kweon. 2019. Development of an electric semi-automatic Chili Pepper transplanter. J. Agric. L. Sci., 53(1): 105-115. https://doi.org/10.14397/jals.2019.53.1.105

Han, L., H. Mao, J. Hu and K. Tian. 2015. Development of a doorframe-typed swinging seedling pick-up device for automatic field transplantation. Span. J. Agric. Res., 13(2): 1-14. https://doi.org/10.5424/sjar/2015132-6992

Han, L., H. Mao, F. Kumi and J. Hu. 2018. Development of a multi-task robotic transplanting workcell for greenhouse seedlings. Appl. Eng. Agric., 34(2): 335-342. https://doi.org/10.13031/aea.12462

He, Y., S. Li, Yang X., Yan H., Wang W., 2016. Kinematic analysis and performance experiment of cam-swing link planting mechanism. Trans. CSAE, 32(6): 34-41.

Hu, J., J. Zhang, J. He and X. Yan. 2013. Motion analysis and experiment for planting mechanism with planetary gears of transplanting machine. Trans. CSAM, 44(10): 57-61.

Ji, J., L. Yang, X. Jin, S. Gao, J. Pang and J. Wang. 2018. Design and parameter optimization of planetary gear- train slip type pot seedling planting mechanism. Trans. CSAE, 34(18): 83-92.

Khadatkar, A., S. M. Mathur and B. B. Gaikwad. 2018. Automation in transplanting: A smart way of vegetable cultivation. Curr. Sci., 115(10): 1884-1892. https://doi.org/10.18520/cs/v115/i10/1884-1892

Kumar, G. V. and H. Raheman. 2008. Vegetable transplanters for use in developing countries: A review. Int. J. Vegetable Sci., 14(3): 232-255. https://doi.org/10.1080/19315260802164921

Kumar, G. V. and H. Raheman. 2011. Development of a walk-behind type hand tractor powered vegetable transplanter for paper pot seedlings. Biosyst. Eng., 110(2): 189-197. https://doi.org/10.1016/j.biosystemseng.2011.08.001

Kumi, F., H. Mao, Q. Li and L. Han. 2016. Assessment of tomato seedling substrate-root quality using x-ray computed tomography and scanning electron microscopy. Appl. Eng. Agric., 32(4): 417-427. https://doi.org/10.13031/aea.32.11443

Lim, J., S. Park, W. Chae, S. Kim, S. Choi, E. Yang, M. Lee, G. Park, Y. Jang, M. Seo and S. Jang. 2017. Seedling conditions for Kimchi Cabbage, Head Lettuce, Cabbage and Broccoli for a riding-type transplanter. J. Biosyst. Eng., 42(2): 104-111. https://doi.org/10.5307/JBE.2017.42.2.104

Liu, Y., H. Mao, T. Wang, B. Li and Y. Li. 2018. Collision optimization and experiment of tomato plug seedling in basket-type transplanting mechanism. Trans. CSAM, 49(5): 143-151.

Mao H., Han L., Hu J., Kumi, F., 2014. Development of a pincette-type pick-up device for automatic transplanting of greenhouse seedlings. Appl. Eng. Agric., 30(4): 547-556. https://doi.org/10.13031/aea.30.10550

Shaw, L. N. 1993. Changes needed to facilitate automatic field transplanting. HortTech., 3(4): 418-420. https://doi.org/10.21273/horttech.3.4.418

Tsuga, K. 2000. Development of fully automatic vegetable transplanter. Jap. Agric. Res. Quart., 34(1): 21-28.

Wang, C., J. Sun, T. Wang and G. Yang. 2014. Development of situations and prospects of vegetable industry of China. North. Hortic., (04): 162-165.

Wang, Y., X. Xia, X. He, X. Zhao and J. Chen. 2017. Dynamics optimization and experiment of planting device driven by planetary eccentric gears and elliptic gears. Trans. CSAM, 48(1): 38-46.

Xu, G., H. Liu, S. Jian, S. Shi and T. He. 2018. Design and test of transplanting mechanism on mulch-film of salvia miltiorrhiza based on five-bar mechanism. Trans. CSAM, 49(9): 55-65.

Yang, Q., G. Huang, X. Shi, M. He, I. Ahmad, X. Zhao and M. Addy. 2020. Design of a control system for a mini-automatic transplanting machine of plug seedling. Comput. Electron. Agric., 169: 1-11. https://doi.org/10.1016/j.compag.2020.105226

Yang, Y., K. C. Ting and G. A. Giacomelli. 1991. Factors affecting performance of sliding-needles gripper during robotic transplanting of seedlings. Appl. Eng. Agric., 7(4): 493-498. https://doi.org/10.13031/2013.26251

Yamamoto, T., K. Matsuo and A. Yamasaki. 2016. Transplant depth of cabbage plug seedlings affects root distribution and anchorage resistance. Sci. Hortic., 213: 144-151. https://doi.org/10.1016/j.scienta.2016.10.010

Yu, G., Z. Liao, L. Xu, P. Zhao and C. Wu. 2015. Optimization design and test of large spacing planetary gear train for vegetable pot-seedling planting mechanism. Trans. CSAM, 46(7): 38-44. ■■

Profitability of Baled Straw as a Fuel in Different Combustion Technologies in Serbia

by
Aleksandar Nesterovic
University of Novi Sad
Faculty of Technical Sciences,
Dept. of Environmental Engineering and
Occupational Safety and Health,
Novi Sad, SERBIA

Djordje Djatkov
University of Novi Sad
Faculty of Technical Sciences,
Dept. of Environmental Engineering and
Occupational Safety and Health,
Novi Sad, SERBIA

Miodrag Viskovic
University of Novi Sad
Faculty of Technical Sciences,
Dept. of Environmental Engineering
and Occupational Safety and Health,
Novi Sad, SERBIA

Savo Bojic
University of Novi Sad
Faculty of Technical Sciences,
Dept. of Environmental Engineering
and Occupational Safety and Health,
Novi Sad, SERBIA

Milan Martinov
University of Novi Sad
Faculty of Technical Sciences,
Dept. of Environmental Engineering
and Occupational Safety and Health,
Novi Sad, SERBIA

Abstract

This research assessed the profitability of the use of baled straw as a fuel in 1 MW boilers compared to a natural gas boiler of the same power in Serbia. Objective was to examine three types of technologies for their different efficiencies, environmental impact, and prices for combusting baled straw, more precisely batch boiler, cigarette, and gasifier. The net present value of the generated costs was used as a measure to assess the profitability of investments in straw bales or natural gas appliances. Assessment was conducted in the BiomasaPro® software tool, intended for assessing the profitability of investment in an energy facility. Only investment in a batch straw bale boiler is profitable compared to a natural gas boiler. In this case, savings could be achieved with a batch boiler without and with a flue gas filter of around 131,000 € and 92,200 €, respectively, after the appliance lifespan. Sensitivity analysis showed that the prices of baled straw could increase by 49% while investing in a batch boiler would remain profitable. At the annual level, the price of baled straw could change up to almost 9% for the same appliance. Subsidy more than 38% of the value of a cigarette boiler would allow for a profitable investment in comparison with a natural gas boiler. With a bank loan investing in a gasifier would not be profitable compared to a natural gas boiler.

Keywords: Baled straw, Biomass, Fuel, Heating, Profitability, Serbia

Introduction

Biomass is considered a favorable source of energy in terms of the impact on climate change because it has a lower carbon footprint compared to fossil fuels (Bourguignon, 2015; Nakada et al., 2014). In the Republic of Serbia, biomass with a share of 60% final energy has the greatest technically usable potential for renewable energy sources, and only 19% has been used (Anonymous, 2013). According to the National Renewable Energy Action Plan of the Republic of Serbia, the available technical potential of biomass is about 3.4 Mtoe (Million Tonnes of Oil Equivalent) per year final energy, of which 1.1 Mtoe is already used (Anonymous, 2013).

Wood is the most common type of biomass that is widely used (Bourguignon, 2015; Glavonjic, 2011). However, there are regions where wood is not readily available or with insufficient quantities to cover the existing solid biomass fuel market (Nilsson et al., 2011). This is typical for rural areas with intensive agriculture (Bojic et al., 2013), where harvest residues are used, due to high availability and lower costs compared to wood and fossil fuels. However, harvest residues have poorer combustion properties compared to woody fuels, due to the significantly higher content of ash and elements such as N, K, S and Cl (Martinov et al., 2011a, Kaltschmitt et al., 2016).

One of the main consequences of an inappropriate combustion process is the potentially higher emission of suspended particles (particulate matter – PM) in flue gases (Schmidl et al., 2011). In addition, emissions of other pollutants and the degree of efficiency largely depend on the boilers themselves, i.e., heating appliances. For example, manual stoking causes incomplete combustion due to the inability to control the process itself, while automation of the combustion process can significantly reduce pollutant emissions in flue gases and increase the energy efficiency (Schmidl et al., 2011).

Straw is the harvest residue of grain crops that can be harvested by a combine harvester, such as cereals, oilseeds, and corn (Kaltschmitt et al., 2016). In this study, the straw bales considered are related to wheat straw. The potential of wheat straw for energy generation is significant because wheat is one of the most widespread field crops in the world (Kim and Dale, 2004). In Serbia, wheat is the second most represented crop, right after corn, so there are significant amounts of wheat straw available, claiming a theoretical potential of about 2.9 Mt (Statistical Office of the Republic of Serbia, 2021). It is estimated that the energy potential of wheat straw in Serbia is about 1.3 Mt or about 475 ktoe, of which in Vojvodina is about 40%, i.e., about 190 ktoe (Martinov and Tesic, 2008; Martinov et al., 2011b). When using wheat straw and in general agricultural biomass as an energy source in Serbia, it is mostly as a solid fuel for residential heating (Martinov et al., 2016).

Wheat straw has a gross calorific value of about 18.5 MJ/kg, while the net calorific value with a moisture content of 15% is about 14.3 MJ/kg (Kaltschmitt et al., 2016). The moisture content during harvest in wheat straw is approximately the same as the moisture content in wheat grain and ranges from 11% to 16% (Dai et al., 2016). The ash content in wheat straw is on average 5.7%, which is lower than that in corn (6.7%), and higher than for corn husks (1.4%) or wood biomass (0.9-1.2%) (Kaltschmitt et al., 2016; Ebeling and Jenkins, 1985).

Baling of straw increases its density. The density of straw in bulk form, with an equilibrium moisture content, has a density of 30 to 50 kg/m^3, depending on the fineness and thickness of the layer (Martinov et al., 2016). In this research, the use of large roll bales (roller bales) was considered, whose density ranges from 80 to 100 kg/m^3 (Kaltschmitt et al., 2016; Martinov et al., 2016).

Energy, economic and environmental assessment for the use of agricultural biomass for combined heat and power (CHP) generation or only for heat generation have been performed. Djurovic et al. (2010) investigated the economic feasibility for the construction of a CHP plant, with a thermal capacity of about 4.8 MW, which would use agricultural biomass, i.e., baled straw, in a cigarette combustion boiler in Serbia. This CHP plant was considered to replace the existing boilers with light fuel oil and fuel oil. Savings of 503,000 € and a simple payback period of 7 years were achieved. Daily savings based on the difference in fuel purchase prices ranged from 1,200 to 2,500 €. Repic et al. (2015) conducted a techno-economic analysis of the replacement of existing fuel oil boilers, with a total thermal power of 9.65 MW, with a biomass boiler, i.e., wood chips or logs. The wood-fired boiler achieved a net present value (NPV) of around 719,000-807,000 €, an internal rate of return (IRR) of around 14-27% and a payback period of 3.2-4.5 years. The log boiler achieved the following results: NPV of about 997,000-1,085,000 €, IRR of about 10-11% and the payback period of 2.9-3.9 years. The same authors stated that savings in CO_2 emissions of about 3,000 t per year would be achieved, which is a significant contribution to the reduction of greenhouse gas emissions.

Objective of the research was to examine whether and under which conditions the use of straw bales as a fuel for boilers of heat output of 1 MW could be profitable in Serbia. The power of the 1 MW boiler was selected in accordance with the Regulation on Limit Values for Emissions of Pollutants into the Air from Combustion Plants of the Government of the Republic of Serbia (Anonymous, 2021a). The small-sized plants for the combustion of solid fuels range up to 1 MW. Therefore, three types of baled straw boilers are considered, i.e., batch, cigarette, and gasifier, which are representatives of three technologies of different energy efficiency, environmental impact, and investment. The profitability of considered combustion technologies was assessed compared to a 1 MW natural gas boiler as a reference and under assumption that they fulfill legal criteria regarding emissions of pollutants in Serbia. Similar research could be conducted in developing countries with high straw potentials or other agricultural biomass types, which could be used as an energy source instead of fossil fuels. This would have a significant environmental contribution, i.e., reduction of greenhouse gas emissions.

Material and Methods

Characteristics, Prices and Costs of Fuel and Heating Appliances

Fuel characteristics, i.e., lower thermal power, moisture content and purchase price are given in the **Table 1**. For data on lower calorific value and moisture content of straw bales, literature data were used

Table 1 Properties and purchase prices of assessed fuels

Fuel	Baled straw	Natural gas
Moisture content, %	15	–
LHV, kWh/kg	3.9	9.3[a]
Purchase price, €/t	40	29.4[b]

[a]kWh/Sm^3; [b]c€/Sm^3

(Martinov et al., 2011a), while for natural gas, data from natural gas distributors were used (Anonymous, 2021b). The purchase price of straw bales was obtained from consumers for large roll bales weighing about 250 kg (Anonymous, 2021c). The market price of natural gas was used (AERS, 2021).

Table 2 shows the technical data of the analyzed boilers, and their investment and operating costs, collected from manufacturers and traders of heating appliances in Serbia (Anonymous, 2021d, 2021e). These data were used to assess the profitability. The manually stoking straw bale boiler was considered coupled with the heat accumulator, in accordance with the recommendations in Martinov et al. (2011a). The same authors state that manually stoking boilers need to be combined with heat accumulators to work as much as possible at rated power to increase the energy efficiency and lower the emissions at power. Gasifier investment costs will be investigated within this study to define the maximal allowed ones that allow profitable operation, since there is no such technology on Serbian market and thus no data available. The gasifier is considered as a potential solution to reduce environmental impact (emissions of pollutants), whereby the goal is to determine the maximum investment cost of such potential technology. Labor costs refer employees to operate and maintain the boiler. Depending on the degree of automation of the appliance, the operating costs differ, so the batch boiler has the highest costs, while the gas boiler has the lowest operating costs.

Profitability Assessment Approach

The profitability assessment was conducted by a software tool designed to assess the justification of investment and decision-making assistance BiomasaPro®, developed by Martinov et al. (2011a). BiomasaPro is made in accordance with the parameters, criteria and rules of the Ministry of Energy and Mining of the Republic of Serbia, defined in the guidelines intended for planning and construction of energy facilities (Lepotic Kovacevic et al., 2010). The BiomasaPro user environment was developed in Microsoft Excel and adapted to potential biomass users (investors), enabling the assessment of the profitability of investments in heating devices for space heating / hot water consumption or process needs.

The BiomasaPro software tool was developed in two variants, construction, and reconstruction. In this paper, a construction variant was used, which refers to the procurement of new equipment and the choice between fossil fuel and biomass, whereby it is possible to compare two different types of biomasses as well.

To conduct an economic feasibility assessment with the help of this software tool, data on fuel characteristics (**Table 1**), thermal energy equipment from producers and traders (**Table 2**), energy needs, and data from the bank (interest rate, payback period) were collected. All this data is used as input for BiomasaPro.

This software provides a comparative overview of investment costs, a comparative overview of heat energy prices and heating costs by year, cumulative heating costs, and the parameters of the assessment derived from the economic flow of the project, i.e., NPV of costs for the construction variant. As a result, the program gives a final verdict of the profitability of the investment. This is based on the investment option that has a lower NPV of all generated costs. Equation (1) defines the NPV costs.

$$NPV = \sum_{i=0}^{n} \frac{B}{1 + d} \qquad (1)$$

Where, B_0 is investment cost; B_i is the generated cost in the n^{th} year, where, i = 1, 2, ..., n; n is the project duration; d is discount rate, which amounts to 1% for financing from own resources, and in case the investment was financed with the entire amount from the loan, then it is equal to the interest rate.

Energy needs are assumed to be 1,500 MWh per year. It is also assumed that the number of straw bales procured is increased by 20% due to the uncertainty of energy needs, i.e., to provide enough fuel and in the case of a season with temperatures below average.

Sensitivity Analysis

A sensitivity analysis was conducted to determine the minimal price of a baled straw that would allow for a profitability. Also, the maximal price of baled straw has been determined, so that the investment in devices that use baled straw remains profitable. In addition, it was examined to what extent after the change (increase or decrease) in

Table 2 Technical data, investment, and operating costs of assessed heating appliances

Appliance	Batch	Cigarette	Gasifier	Natural gas
Power, kW	850	1,000	1,000	1,000
Stoking	Manual	Automatic	Automatic	Automatic
Fuel	Baled straw	Baled straw	Baled straw	Natural gas
Annual efficiency, %	55	80	85	95
Lifespan, years	10	20	20	20
Investment cost, €	24,000	350,000	na	40,738
Installation/testing, €	250	250	250	562
Maintenance, €	600	8,750	6,277	1,018
Labor costs, €	10,800[a]	5,400[b]	5,400[b]	900[c]
Material costs, €	300	400	300	100

[a]600 € × 6 month × 3 pers; [b]600 € × 6 month × 1.5 pers; [c]600 € × 6 month × 0.25 pers; na: not available

the price of baled straw on an annual level, investment in devices that use baled straw remains profitable, i.e., it becomes profitable if that was not the case. It was examined how the financing of the project from a bank loan affects its profitability. Financing 100% of the project from the loan was considered, with a payback period of 7 years and an interest rate of 5.84%, and this loan is for the use of energy efficient and renewable energy sources (Anonymous, 2021f). Finally, the minimum required subsidies are set if the use of straw bales is not assessed as profitable, both for the renewable energy produced and for the investment costs.

A batch straw boiler with a cyclone and a fabric filter has been compared to a boiler that also uses natural gas. The additional investment cost of the flue gas filter with installation was 17,500 €. Also, there was an increase in maintenance costs by 438 € and material costs by 100 €.

Results and Discussion

The results of the profitability assessment for the three types of baled straw appliances are presented in the following table (**Table 3**). The results show that investing in a batch boiler without and with a filter is profitable compared to a corresponding natural gas boiler. In this way, around 131,000 € and 92,200 € could be saved during the exploitation period (10 years). A comparison of a cigarette boiler with a gas one, shows that the investment in the former generates around 252,900 € more costs after 20 years. As already mentioned in subsection 2.1.1, the investment in the gasifier is on the verge of profitability after 20 years. The price of the gasifier, in that case, should be 251,066 €.

The sensitivity analysis to the maximal allowed relative change in the purchase price of baled straw that allow for profitability is given in **Table 4**. The results show that baled straw prices when used in a batch boiler with and without a filter, could be approximately more than 35% to 50% of actual market prices. In contrast, baled straw prices when used for a cigarette boiler, would have to be reduced by about 73% to achieve profitability. Any reduction in the price of a baled straw for a gasifier could not enable a profitable investment compared to natural gas. The reason for this is the price of the gasifier itself, which is set to provide zero profitability.

Table 5 presents the sensitivity analysis to annual changes in the price of baled straw throughout the project duration. The change in prices starts from the second project year and is expressed as a percentage. The results show that the prices of baled straw, if used in a batch boiler without and with a filter, could increase by about 7% to 9% annually and that further investment in these appliances would be profitable. In contrast, the prices of baled straw, when used for a cigarette boiler, would have to be decreased by approximately 20%, to pay off the investment in a cigarette boiler. Any increase in price on the annual level of baled straw for the gasifier could not allow a profitable investment compared to natural gas, for the same reasons as in the previous sensitivity analysis.

Sensitivity analysis of project financing from a bank loan is given in **Table 6**. The results show that when the project is financed entirely by the bank loan, the investment remains justified only for batch boilers. The investments in a cigarette boiler and gasifier are not justified,

Table 3 Profitability assessment parameters

Appliance 1-2		NPV1 – NPV2, €	Viable
Batch	Natural gas	–131,014	YES
Batch + F	Natural gas	–92,192	YES
Cigarette	Natural gas	252,849	NO
Gasifier	Natural gas	–1	YES

NPV1 – NPV2: The difference between NPV costs between baled straw and natural gas; F: Flue gas purification filter

Table 4 Sensitivity analysis of baled straw fuel purchase prices

Appliance 1-2		Price change, %
Batch	Natural gas	+49
Batch + F	Natural gas	+35
Cigarette	Natural gas	–73
Gasifier	Natural gas	nr

F: Flue gas purification filter; nr: not relevant.

Table 5 Sensitivity analysis of the annual change in the purchase price of baled straw

Appliance 1-2		Annual price changes, %
Batch	Natural gas	+8.9
Batch + F	Natural gas	+6.6
Cigarette	Natural gas	–19.8
Gasifier	Natural gas	nr

F: Flue gas purification filter; nr: not relevant.

Table 6 Sensitivity analysis of financing sources

Appliance 1-2		NPV1 – NPV2, €	Viable
Batch	Natural gas	–104,512	YES
Batch + F	Natural gas	–68,916	YES
Cigarette	Natural gas	311,354	NO
Gasifier	Natural gas	105,667	NO

NPV1 – NPV2: The difference between NPV costs between baled straw and natural gas;F: Flue gas purification filter since the additional costs generated due to the loan are significantly higher for these two biomass boilers than for the natural gas boiler.

The following table (**Table 7**) presents the sensitivity analysis regarding the minimum required subsidies for a profitable investment. Subsidies refer to the generated renewable energy or for the investment costs of equipment that uses renewable sources. For the cigarette, needed subsidies rate 14,250 € per year, i.e., about 9.4 € per MWh of generated renewable thermal energy. Also, subsidy of about 38% of the investment costs would allow profitable investment in a cigarette boiler.

Table 7 Sensitivity analysis of subsidies

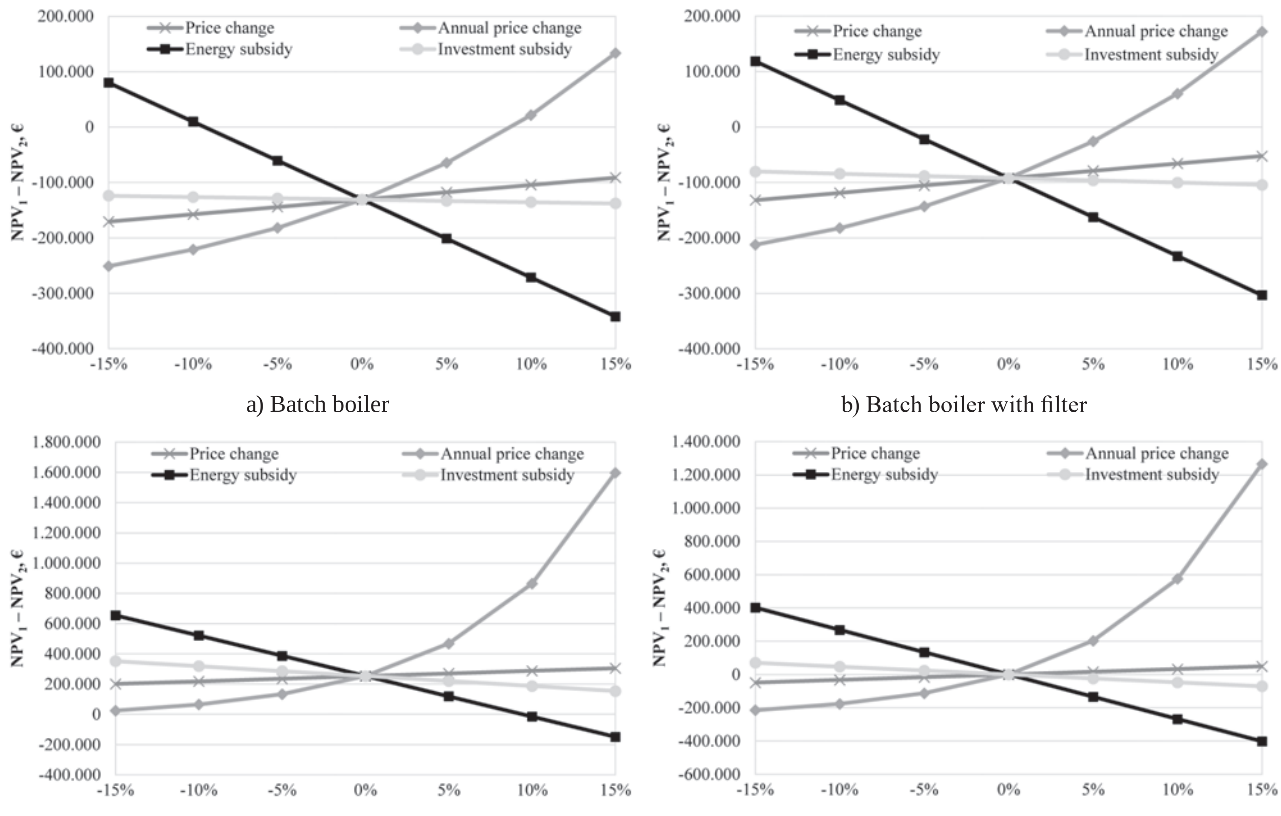
Appliance 1-2		Subsidy: energy		Subsidy: investment
		€/MWh	€/year	%
Cigarette	Natural gas	9.44	14,250	38.4

Figure 1 shows the sensitivity analysis of the NPV difference depending on the variations of considered factors for all types of appliances. The steeper the lines, the more sensitive the NPV difference is to this factor. The point of intersection of all lines represents the reference case. It is noticed that the change in fuel prices and investment subsidies in all cases have no large influence. In contrast, energy subsidies and the annual change in straw purchase prices in all the cases have a significantly larger influence. For example, the difference in NPV was for the minimum (−15%) value of the annual change in baled straw prices −251,079, −212,257, 24,477 and −214,939 €, and for the maximum (15%) 133,356, 172,179, 1,597,470 and 1,265,524 €, for batch boiler without and with filter, cigarette boiler, and gasifier, respectively. Also, the change in the difference of NPV, when it comes to energy subsidies for the minimum (−15%) value is 79,980, 118,802, 654,854 and 402,004 €, and for the maximum (15%) −342,009, −303,187, −149,156 and −402,006 €, for batch boiler without and with filter, cigarette boiler, and gasifier, respectively.

Conclusions

The profitability assessment shows that only batch baled straw boilers are profitable, regardless of the method of financing. Also, as part of the sensitivity analysis, it was noticed that there may be significant increases in fuel prices and that investing in batch boilers with and without filters remains profitable. Due to the lack of prices for baled straw gasifiers, the price is set so that it is on the verge of profitability, which leads to the fact that profitability is very sensitive

Fig. 1 Sensitivity analysis– relative increase of investigated parameters



a) Batch boiler

b) Batch boiler with filter

c) Cigarette boiler

d) Gasifier

to the increase in the price of baled straw, and the way of financing the project itself. Due to the unjustified investment in a cigarette boiler, it is necessary for the price of baled straw on the market to decrease, which cannot be expected since it is expected that in the future the price of baled straw on the market will only increase. Another option is to achieve profitability with some of the considered types of subsidies. Borrowing for this type of appliance would only further increase costs.

Future research should focus on a comprehensive assessment of the availability of fuel on the market and its acceptability by users. Also, assessment of the impact on the environment from the aspect of the impact on climate change and the emission of air pollutants caused by combustion. This would provide a comprehensive picture of whether baled straw is suitable for use as fuel, as well as the appliances themselves considered in this study.

Acknowledgements

This research was financed by the project of the Department of Environmental Engineering and Occupational Safety and Health at the Faculty of Technical Sciences? Development of innovative engineering approaches to improve the environment and occupational safety (*Razvoj inovativnih inženjerskih pristupa za unapređenje stanja životne i radne sredine*).

REFERENCES

AERS. 2021. Energy Agency of the Republic of Serbia − Regulation of natural gas prices. https://www.aers.rs/Index.asp?l=1&a=22.05&tp=TarifeG. (June 2021).

Bojic, S., Dj. Djatkov, D. Brcanov, M. Georgijevic and M. Martinov. 2013. Location allocation of solid biomass power plants: Case study of Vojvodina. Renew Sust Energ Rev, 26: 769-775.

Bourguignon, D. 2015. Biomass for electricity and heating − Opportunities and challenges, Report No. PE 568.329. European Parliamentary Research Service, Brussels, Belgium.

Dai, J., B. Bean, B. Brown, W. Bruening, J. Edwards, M. Flowers, R. Karow, C. Lee, G. Morgan, M. Ottman, J. Ransom and J. Wiersma. 2016. Harvest index and straw yield of five classes of wheat. Biomass Bioenergy, 85: 223-227.

Djurovic, D., D. Dakic, B. Repic, S. Nemoda, G. Zivkovic and A. Eric. 2010. Economic feasibility of building a facility for combined heat and power production using agricultural biomass. Cont. Agr. Engng, 36(4): 373-381.

Ebeling J. M. and B.M. Jenkins. 1985. Physical and chemical properties of biomass fuels. ASAE, 28(3): 898-902.

Glavonjic, B. D. 2011. Consumption of wood fuels in households in Serbia ? present state and possible contribution to the climate change mitigation. Thermal Science, 15(3): 571-585.

Kaltschmitt, M., H. Hartmann and H. Hofbauer. 2016. Energie aus Biomasse − Grundlagen, Techniken und Verfahren. Springer-Verlag, Berlin.

Kim, S. and B.E. Dale. 2004. Global potential bioethanol production from wasted crops and crop residues, Biomass Bioenerg, 26(4): 361-375.

Lepotic Kovacevic, B., D. Stojiljkovic and B. Lazarevic. 2010. Construction of Plants and Electricity/Heat Generation from Biomass in the Republic of Serbia − Guide for Investors, Ministry of Mining and Energy of Republic of Serbia, Beograd, Serbia.

Martinov, M., M. Viskovic, S. Bojic, B. Dumnic, M. Golub and J. Krstic. 2016. Studija prostornog razmeštaja namenskih javnih skladišta agrarne biomase na teritoriji AP Vojvodine (Study of the spatial distribution of dedicated public warehouses of agricultural biomass on the territory of AP Vojvodina, in Serbian). Faculty of Technical Sciences., Novi Sad, Serbia.

Martinov, M., Dj. Djatkov, J. Krstic, G. Vujic, M. Golub, M. Brkic and S. Bojic. 2011a. Program za ocenu ekonomskih pokazatelja za energetsku primenu biomase (Calculator for Profitability Assessment of Biomass Utilization for Energy Generation, in Serbian). Faculty of Technical Sciences., Novi Sad, Serbia.

Martinov, M., M. Brkic, T. Janjic, Dj. Djatkov and M. Golub. 2011b. Biomass in the Province Vojvodina − RES 2020. Cont. Agr. Engng., 37(2): 119-134.

Martinov, M. and M. Tesic. 2008. Cereal/soybean straw and other crop residues utilization as fin Serbia-status and prospects. In Scarlat, N., Dallemand, J. F. and M. Martinov ed.: “Cereals straw and agricultural residues for bioenergy in European Union New Member States and Candidate Countries”, European Commission, Joint Research Centre, Institute for Environment and Sustainability, Novi Sad, Serbia, 2-3 October 2007, Book of Proceedings, 45-56.

Nakada, S., D. Saygin and D. Gielen. 2014. Global Bioenergy Supply and Demand Projections: A working paper for REmap 2030. International Renewable Energy Agency, Abu Dhabi, United Arab Emirates.

Nilsson, D., S. Bernesson and P. A. Hansson. 2013. Pellet production from agricultural raw materials ? A systems study. Biomass Bioenerg, 35(1): 679-689.

Repic, B., D. Djurovic, M. Paprika, and D. Dakic. 2015. Technical and economical justified replacement of existing crude oilboiler with new biomass boiler in central heating system. Cont. Agr. Engng, 41(4): 189-196.

Statistical Office of the Republic of Serbia. 2021. Database of the Statistical Office of the Republic of Serbia. https://data.stat.gov.rs/Home/Result/130102?languageCode=sr-Cyrl. (June 2021).
Schmidl, C., M. Luisser, E. Padouvas, L. Lasselsberger, M. Rzaca, C. Ramirez-Santa Cruz, M. Handler, G. Peng, H. Bauer and H. Puxbaum. 2011. Particulate and gaseous emissions from manually and automatically fired small scale combustion systems. Atmospheric Environment, 45(39): 7443-7454.
Anonymous. 2021a. Uredba o graničnim vrednostima emisija zagađujućih materija u vazduh iz postrojenja za sagorevanje: 6/2016-55, 67/2021-21 (Regulation on emission limit values for air pollutants from combustion plants: 6/2016-55, 67/2021-21, in Serbian). Official Gazette of the Republic of Serbia 6/2016-55, 67/2021-21.
Anonymous. 2021b. Novi Sad – Gas DOO, information on natural gas. http://www.novisadgas.rs/korisnici/. (March 2021)
Anonymous. 2021c. KNOTT Autoflex YUG DOO, Bečej, personal contact. (March 2021).
Anonymous. 2021d. ATI-Terming DOO, Kula, Branislav Banatski, personal contact, (March 2021).
Anonymous. 2021e. Top Therm DOO, Bečej, Arpad Balog, personal contact, (March 2021).
Anonymous. 2021f. UniCredit Bank Serbia. Credit for energy efficiency. https://www.unicreditbank.rs/rs/pi/kredit/energetska_efikasnost.html#reprezentativniprimer. (March 2021).
Anonymous. 2013. National Renewable Energy Action Plan of the Republic of Serbia (In accordance with the template foreseen in the Directive 2008/29/EC − Decision 2009/548/EC). Ministry of Energy, Development and Environmental Protection, Belgrade, Serbia.

■■

Farm Mechanization in India: Status and Way Forward

by

C. R. Mehta*
Director
ICAR - Central Institute of Agricultural Engineering,
Bhopal - 462038, INDIA
*Corresponding Author: crmehta65@yahoo.co.in

R. A. Bangale
Senior Research Fellow
All India Coordinated Research Project on Farm Implements and Machinery,
ICAR - Central Institute of Agricultural Engineering,
Bhopal - 462038, INDIA
rash.gayatri@gmail.com

N. S. Chandel
Senior Scientist
Agricultural Mechanization Division,
ICAR - Central Institute of Agricultural Engineering,
Bhopal – 462038, INDIA
narendracae@gmail.com

Mohit Kumar
Senior Research Fellow
All India Coordinated Research Project on Farm Implements and Machinery,
ICAR - Central Institute of Agricultural Engineering,
Bhopal - 462038, INDIA
mohit130794@gmail.com

Abstract

During the last five decades, India has made considerable progress in farm mechanization. The status of farm power availability and agricultural mechanization for different crops and agricultural operations along with its impact are assessed in this study. The power available from agricultural workers, draught animals, tractors, power tillers, diesel engines and electric engines were 0.08, 0.07, 1.93, 0.02, 0.37, and 0.57 kW/ha, respectively in 2021-22. During the year 1971-72, animate power dominated with 69% share in total available farm power for agricultural operations, whereas, mechanical power dominated with 95% share in total farm power availability of 3.04 kW/ha in 2021-22. The states of Punjab, Haryana and Bihar have higher farm power availability than the rest of the states. On the other hand, the north eastern states of India have the lowest farm power availability as compared to other states. With focus to bring more area under irrigation in India, the power available per hectare irrigated area for ground water and surface water lifting has increased from 0.73 kW in 1993-94 to 1.43 kW in 2017-18. The share of electric pump for irrigation purpose increased to 76% in 2017-18. During last 17 years, the area under micro-irrigation has increased at 9.2% compound annual growth rate (CAGR) to 13.78 Mha in 2022. The sprinkler irrigation covered 7.1 Mha area while drip irrigation covered 6.32 Mha area. The overall farm mechanization level of the country was 47% in 2021-22. The wheat, rice, maize are the highly mechanized crops with overall mechanization levels of 69, 53 and 46%, respectively and followed by pulses (41%), oil seeds (39%), cotton (36%), sugarcane (35%) and sorghum and millets (33%). As a result of farm mechanization, various power sources and improved farm equipment were utilized to reduce drudgery and workload, to increase precision of the operation and on time utilization of various crop inputs and to reduce losses at different stages of crop production. It also helped in saving of inputs, increased cropping intensity, reduced cost of operation and reduced post-harvest losses resulting into high grain quality and yield.

Keywords: Farm power, Tractor density, Mechanization level, Mechanization impact, Water lifting devices, Precision farming

Introduction

India accounts for only about 2.5% of the world's geographical area and 4% of its renewable water resources, but has to support about 18% of the world's human population and 17% of livestock (Mehta et al., 2014; Maan and Chaudhry, 2019). Agriculture is an important sector of Indian economy, accounting for 20.2% of the nation's GDP and about 14.30% of its export worth Rs. 3088 billion during 2020-21 (Anonymous, 2022). There was a record food-grain production of 315 million tonne during 2021-22. Even though the Indian agricultural system has seen a remarkable success in the production of food-grains and allied sector, it has not provided an expected level of compensation to farmers.

Indian agriculture is characterized by its small and marginal land holdings. During 2015-16, 86.08% of the total land holdings were below 2 ha accounting for 47% of the total cultivated area. Semi-medium and medium land holdings (2-10 ha) were only 13.35% with 44% cultivated area. However, the large holdings (10 ha and above) were merely 0.57% of total number of holdings with 9.07% cultivated area (Anonymous, 2019a). Fragmentation of farm land holdings is a major concern (Tiwari et al., 2019) and an average size of operational holding has declined from 2.28 ha in 1970-71 to 1.08 ha in 2015-16.

The agricultural mechanization plays a significant role of catalyst in enhancing agricultural production (Mehta et al., 2014). It also enables farmers to use available farm power precisely to produce quality and higher production. It facilitates timely use of inputs efficiently and reduces the drudgery associated with farm operations. The mechanization level in Indian agriculture is still low as compared to the other developed countries, which provides a lot of potential for mechanization (Anonymous, 2019b). Therefore, a complete insight of farm mechanization status is necessary to assess the need of further advancement in farm mechanization and power availability.

Implements for seedbed preparations, sowing/planting, transplanting, irrigation, plant protection, harvesting and threshing have been widely adopted by the Indian farmers despite small land holding size (Anonymous, 2020b). Nowadays, farmers with small land holdings have been utilizing selected improved farm machinery through custom hiring to increase productivity and to reduce the cost of cultivation. The increased use of improved agricultural machinery has led to increase in cropped area, cropping intensity and crop production of the country (Anonymous, 2020b). In addition to its dominant contribution to the multiple cropping systems and diversification of agriculture, mechanization also enables effective utilization of inputs such as seeds, fertilizers and irrigation water (Mehta et al., 2014). Mechanization also helps to diversify the Indian agriculture from conventional to commercial crops. Sub-Mission on Agricultural Mechanization (SMAM), the scheme of farm mechanization by Government of India (GoI) resulted in adoption of farm machinery such as tractors, power tillers, combine harvesters, irrigation pumps, plant protection equipment, threshers, improved implements and hand tools (Mehta et al., 2014; Anonymous, 2020b).

This paper discusses the current status of available farm power sources, mechanization level for different crops for different farm operations, trend in farm machinery market and impact of farm mechanization on farming community in India. It also briefs about way forward for farm mechanization in India.

Farm Power Availability (FPA)

The use of farm machinery depends upon the farm power sources available in the country for various tractive and stationary operations. The sources of power available in Indian farms for various farm operations include mobile sources viz. human (men, women), draught animals (bullocks, camels, horses, ponies, mules and donkeys), tractors, power tillers and self-propelled machinery (combines, reapers, sprayers etc.); and stationary sources viz. diesel/oil engines and electric motors for pump sets, threshers, sprayers, etc.

The time-series data of farm power sources and food-grain production of India were compiled and used in the study. The secondary data related to food-grain productivity, cropping intensity, net sown area and other relevant agriculture statistics were collected and compiled from various sources such as Agricultural Statistics and Agriculture Census published by the Department of Agriculture and Farmers Welfare, GoI. The data on population of agricultural workers and draught animals were collected and compiled from the Population Census (2011), National Institution for Transfoming India (NITI) Aayog Discussion Paper (1/2022) and Livestock Census (2019) published by the GoI. The data on population of tractors and power tillers were collected and compiled from Tractor and Mechanization Association (TMA)

Table 1 Farm power availability from different sources in India

Year	Power, kW/ha						Total power, kW/ha
	Agric. workers	Draught animals	Tractors	Power tillers	Diesel engines	Electric motors	
1971-72	0.045	0.212	0.020	0.001	0.053	0.041	0.372
1975-76	0.048	0.209	0.040	0.001	0.078	0.056	0.432
1981-82	0.051	0.206	0.090	0.002	0.112	0.084	0.545
1985-86	0.057	0.204	0.140	0.002	0.139	0.111	0.653
1991-92	0.065	0.193	0.230	0.003	0.177	0.159	0.827
1995-96	0.071	0.182	0.320	0.004	0.203	0.196	0.976
2001-02	0.079	0.172	0.480	0.006	0.238	0.25	1.225
2005-06	0.087	0.155	0.700	0.009	0.273	0.311	1.535
2011-12	0.100	0.134	0.804	0.012	0.295	0.366	1.711
2015-16	0.076	0.111	1.265	0.018	0.330	0.541	2.341
2021-22	0.082*	0.075	1.932	0.020*	0.368*	0.568*	3.045

* Estimated

and Power Tiller Manufacturers Association (PMA), respectively. The data on population of diesel engines and electric pump sets/motors were collected from CIAE Data Book 2021 (Anonymous, 2021). The data on water lifting devices and micro-irrigation systems were collected from I, II, III, IV, V and VI Minor Irrigation Censuses (GoI) and Agricultural Statistics at a Glance (GoI), Ministry of Agriculture & Farmers Welfare (MoA & FW), respectively.

The power availability from different farm power sources was calculated by taking an average power of 0.05, 0.38, 5.60, 3.70 and 5.60 kW for an agricultural worker, draught animal, power tiller, electric motor and diesel engine, respectively (Anonymous, 2020b). However, power availability from tractor was estimated by taking an average power of 13.4, 18.7, 26.1, 33.6 and 41.0 kW for the power range of < 15, 15-22, 23-30, 31-37 and >37 kW, respectively (Mehta et al., 2014). The life of tractor, power tiller, combine harvester, electric motor and diesel engine was considered as 15, 10, 6, 15 and 15 years, respectively.

Total power availability on Indian farm was calculated by dividing sum of total available power by total net sown area in million ha of that particular year (Mehta et al., 2014; Mehta et al., 2019). The available farm power in kilowatt per hectare in Indian agriculture from different power sources along with total farm power is presented in **Table 1**. It indicates that during the last 50 years, there has been a considerable change in the relative proportion of various sources of power available for agricultural operations. The total power availability on Indian farms has increased at a Compound Annual Growth Rate (CAGR) of 4.3% from 0.372 in 1971-72 to 3.045 kW/ha in 2021-22. The availability of draught animal power has come down from 0.212 kW/ha in 1971-72 to 0.075 kW/ha in 2021-22, whereas, the power available from agriculture workers, tractors, power tillers, diesel engines and electric motors has increased from 0.045 to 0.082, 0.02 to 1.932, 0.001 to 0.020, 0.053 to 0.368 and 0.041 to 0.568 kW/ha, respectively during the same period (**Table 1**). Farm power available per unit cultivated land in India is still very low as compared to South Korea, Japan and United States of America (Tiwari et al., 2019).

The dominant share of draught animals in Indian farm power has been observed until 1985-86. Afterwards, the tractive power has become dominant with share of 63% in 2021-22 (**Fig. 1**). During the period from 1971-72 to 2021-22, the available human power per hectare has increased from 0.045 kW to 0.082 kW (**Table 1**). However, its proportion in the total farm power has experienced a decline from 12.1% to 2.7% during the period. The share of available power from power tillers has increased from 0.3% to 0.7% from 1971-72 to 2021-22. Similarly, the share of available power from electric motors has also increased from 11.0% to 18.7%, during the same period. However, the share of available power from diesel engines has decreased from 14.2% to 12.1% during the same period (**Fig. 1**). Though, the Indian agriculture is represented by marginal and small land holdings, the share of power tillers has been observed to be less than one percent so far.

Fig. 1 Trend in use of power sources in Indian agriculture

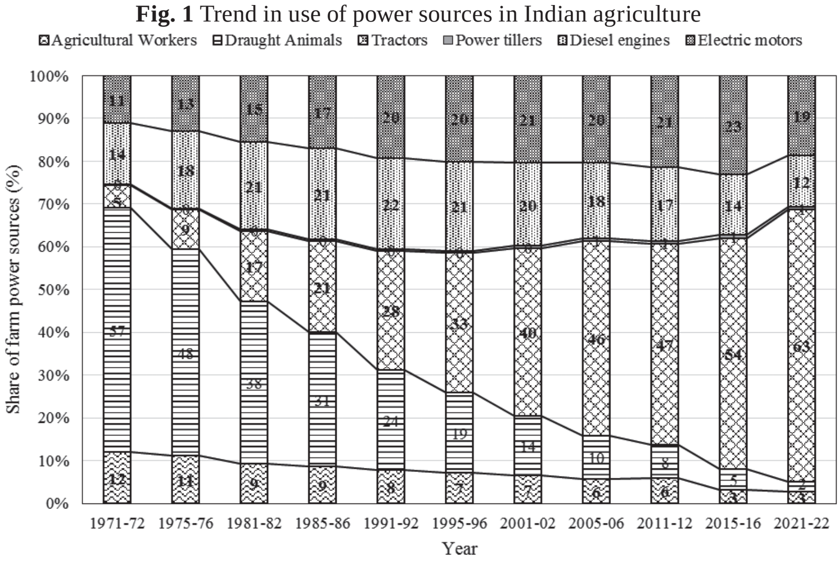


Table 2 Cropping intensity and power availability on Indian farms

Year	Cropping intensity, %	Food-grain productivity, t/ha	Power available, kW/ha	Power per unit production, kW/t	Net sown area per tractor, ha
1975-76	120.00	0.94	0.432	0.46	487
1985-86	127.00	1.18	0.653	0.55	174
1995-96	131.00	1.50	0.976	0.65	84
2005-06	132.00	1.65	1.535	0.93	47
2015-16	141.25	1.80	2.341	1.30	22
2021-22	141.60	2.27	3.045	1.34	15

During 1975-76, the cropping intensity was 120% with power availability of 0.43 kW/ha and increased to 141.6% with increase in power availability to 3.045 kW/ha in 2021-22 (**Table 2**). It indicated that increase in power availability resulted in higher cropping intensity in Indian agriculture. The power availability per unit food-grain production has increased from 0.46 kW/t to

1.34 kW/t during last forty-six years (**Table 2**). The net sown area per tractor indicated the reverse trend during the same period. It was 487 hectare per tractor in 1975-76 and reduced to 15 hectare per tractor in 2021-22.

2.1 State-wise Farm Power Availability

In order to study the trend in state-wise farm power availability, the states of India have been divided into four categories on the basis of farm power availability (FPA) in 2018-19 (Anonymous, 2020b). As shown in **Fig. 2**, the category I has FPA more than or equal to the national average of 2.50 kW/ha; Category-II has FPA between 1.75 and 2.50 kW/ha; Category III has FPA between 1.00 and 1.75 kW/ha and Category IV has FPA less than 1.00 kW/ha (Anonymous, 2020b). The north eastern states of India have low farm power available for the agricultural operations as compared to other parts of India. States of Punjab, Haryana, Bihar, Uttar Pradesh, Tamil Nadu, Telangana, Uttarakhand and Gujarat have farm power availability of 6.00, 5.50, 3.50, 3.49, 3.46, 3.41, 3.05 and 3.00 kW/ha, respectively which was more than or equal to national average and grouped under category I. This may be due to high density of tractors in these states. The states in second category are Andhra Pradesh, Karnataka, West Bengal, Madhya Pradesh, Odisha and Rajasthan with farm power availability of 2.49, 2.44, 2.12, 2.00, 1.98 and 1.82 kW/ha, respectively. The states in third category are Tripura, Chhattisgarh, Maharashtra, Jharkhand, Himachal Pradesh, Jammu & Kashmir, Kerala and Assam with farm power availability of 1.63, 1.46, 1.45, 1.34, 1.32, 1.32, 1.25 and 1.20 kW/ha, respectively. The fourth category is of states of Mizoram (0.69 kW/ha), Sikkim (0.69 kW/ha), Manipur (0.65 kW/ha), Nagaland (0.61 kW/ha), Arunachal (0.58 kW/ha) and Meghalaya (0.37 kW/ha). The low FPA in north eastern states may be due to the low density of tractors due to hilly terrain and very small land holding size. This has become a major impediment for successful mechanization in these states (Anonymous, 2019b).

State-wise variation in FPA is relatively high and many states fall behind the national average. The level of FPA in the states varies from 0.37 kW/ha (Meghalaya) to 6.00 kW/ha (Punjab) (Anonymous, 2020b). Moreover, each state has district-wise variations in FPA. Although both Punjab (6.0 kW/ha) and Haryana (5.5 kW/ha) states have achieved national target of FPA of 4.0 kW/ha by 2030 (Anonymous, 2018), the inter district variation is between 0.45-13.88 kW/ha and 2.41-10.13 kW/ha in Punjab and Haryana, respectively (Anonymous, 2020b). Regardless of the state's average FPA, such variations occur in all states.

2.2 Dynamics of Farm Power Sources

During 1971-72, Indian agriculture was dominated by draught animal power with 57% share and followed by diesel engine (14%), human power (12%), electric motors

Table 3 Share of tractive power over total farm power in India

Year	Net sown area (Mha)	Total farm power (MkW)	Animate power (%)	Electro-mechanical power (%)	Tractive over total power (%)
1971-72	140.30	52.13	68.96	31.04	5.38
1981-82	140.00	76.36	47.23	52.77	16.51
1991-92	143.00	118.29	31.76	68.24	28.29
2001-02	140.73	172.44	20.69	79.31	39.51
2011-12	141.00	241.22	13.62	86.38	46.83
2021-22	139.35	424.32	5.16	94.84	63.45

Fig. 2 Farm power availability in different states of India during 2018-19

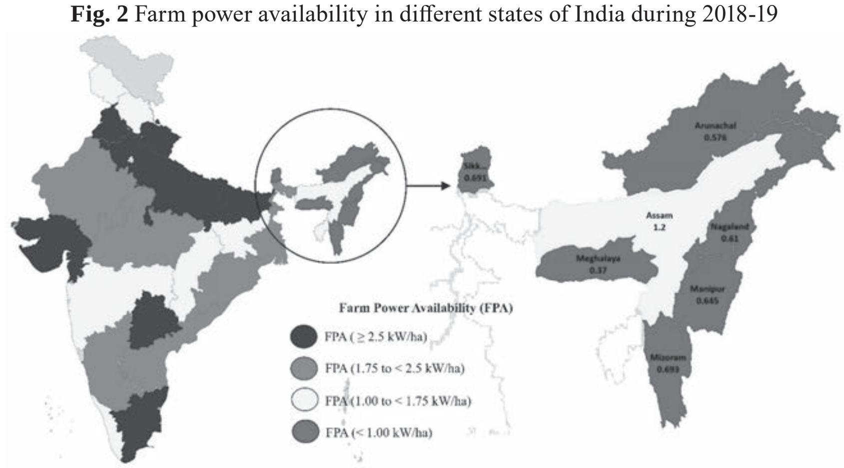
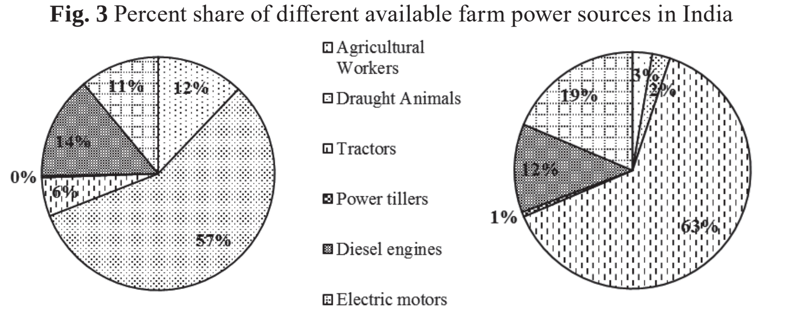


Fig. 3 Percent share of different available farm power sources in India



(a) Year 1971-72 (b) Year 2021-22

Table 4 Population, available power and intensity of animate power sources

Year	Agricultural workers			Draught animals		
	Population (Million)	Power (Million kW)	Intensity (No. per 1000 ha)	Population (Million)	Power (Million kW)	Intensity (No. per 1000 ha)
1971-72	125.70	6.285	890	78.41	29.79	557
1981-82	148.00	7.400	1,050	76.20	28.95	543
1991-92	185.30	9.265	1,300	72.63	27.59	508
2001-02	234.10	11.705	1,660	64.09	24.35	453
2011-12	263.10	13.155	1,860	49.64	18.86	352
2021-22	228.53	11.426	1,640	27.52	10.46	197

(11%), tractors (6%) and power tillers (< 1%) (**Fig. 3**). However, during 2021-22, the trend changed with dominance of tractor power with 63% share and followed by electric motors (19%), diesel engines (12%), human power (3%), draught animals (2%) and power tillers (1%) (**Fig. 3**). Animate power contributed 69% of total farm power in 1971-72 and mechanical along with electrical power contributed to 31% only. In 2021-22, the contribution from animate power reduced to 5.16% while the mechanical along with electrical power increased to 94.84% (**Table 3**). The contribution of tractive power over total power was 5.38% in 1971-72 and increased to 63.45% in 2021-22.

2.2.1 Human Power

The agriculture and allied sector provided employment to 40% male workers, 60% female workers and 45.6% of work force during 2019-20 (Chand & Singh, 2022). Agricultural workers comprise of cultivators and agricultural laborer.

The population of agricultural workers in India increased from 97.2 million in 1951 to 233.3 million in 2020, but it was reduced from 263.1 million in 2011 to 233.3 million in 2020 (**Fig. 4**). Of the total agricultural workers in 1991, 74 million (35%) is comprised of women agricultural workers which increased to 86.2 million (37%) during 2020 (**Fig. 4**) (Chand & Singh, 2022). The participation of women in agriculture is increasing but men continue to dominate the agriculture workforce with 63% share (**Fig. 4**) (Chand & Singh, 2022). The age-wise estimate of the workforce reveals a sizeable increase in the number of youths working in 2019-20 (Chand & Singh, 2022). The power available from human has increased at a CAGR of 1.2% from 0.045 kW/ha (6.28 Million kW) in 1971-72 to 0.082 kW/ha (11.43 Million kW) in 2021-22 (**Table 4**). The worker intensity has increased from 0.90 to 1.64 workers/ha during the same period (**Table 4**).

2.2.2 Animal Power

Traditionally, draught animals have been used in India for field operations, transport and agro-processing. The small and marginal farmers mainly rely on draught animals and human power for farm operations. Over the years, the annual utilization of draught animals as a farm power source has decreased (Tiwari et al., 2019). However, in hill regions and some difficult terrains, the field operations are in general being performed by human and animal power sources.

The population of draught animals, which was 78.41 million in 1971-72, has been showing a declining trend with estimated population of 27.52 million in 2021-22 (**Table 4**). Particularly, cattle population has reduced from 54.63 million in 2007 to 33.44 million in 2019 (**Fig. 5**). During 2021-22, the area for per unit availability of animal pair has increased to 10 ha from 3.59 ha in 1971-72. The power available from draught animal has decreased at negative CAGR of 2% from 0.212 kW/ha (29.79 million kW) in 1971-72 to 0.075 kW/ha (10.46 million kW) in 2021-22 (**Table 4**). The decrease in animal power is largely due to increase in use of electro-mechanical power sources. Animals are still the main source of power in hilly areas, for marginal farmers and for short distance transport.

2.2.3 Tractor

In the farm mechanization, tractor power has been a dominant power source since 1991-92 (**Fig. 1**). The

Fig. 4 Involvement of human population in Indian agriculture

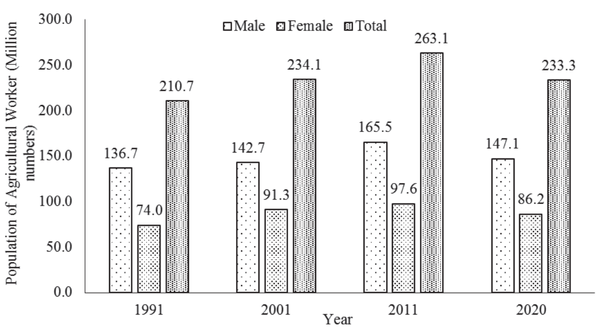
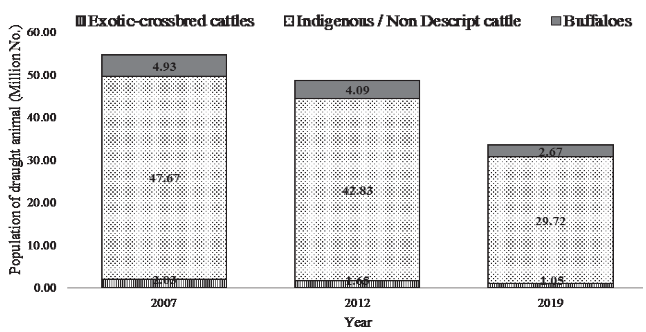


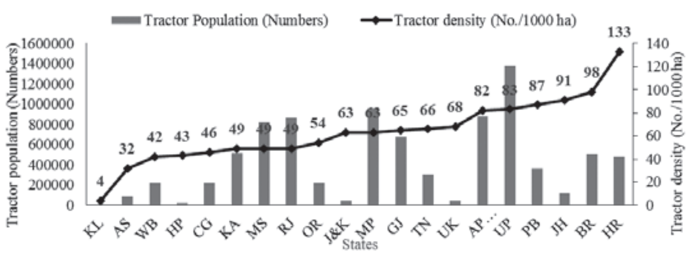
Fig. 5 Major draught animal population in India based on livestock census



power available from tractor for agricultural works has increased at a CAGR of 8.58% from 0.02 kW/ha (4.38 million kW) in 1971-72 to 1.932 kW/ha (269.26 million kW) in 2021-22 (**Tables 1** & **5**). Tractor population has increased sharply from 0.168 million in 1971-72 to 9.173 million in 2021-22 (**Table 5**). During 2021-22, the command area per tractor has decreased to 15 ha from 1000 ha during 1971-72. During 2021-22, Uttar Pradesh has the highest tractor population and followed by Madhya Pradesh, Andhra Pradesh (including Telangana), Rajasthan and Maharashtra (**Fig. 6**). These states may have larger proportion of agricultural land and a higher prevalence of mechanized farming practices leading to increased tractor adoption. On the other hand, Haryana has the highest tractor density of 133 tractors per thousand hectare of net sown area and followed by states of Bihar (98), Jharkhand (91), Punjab (87), Uttar Pradesh (83), Andhra Pradesh (including Telangana) (82) and Uttarakhand (68) (**Fig. 6**). It might be due to relatively smaller net sown area, availability of irrigation facilities, and government support for mechanization. However, the lowest tractor density is in Kerala (4) and followed by Assam (32), West Bengal (42) and Himachal Pradesh (43) among the states of India. The low tractor density in these states can be attributed to their diverse topographies, which include challenging terrains or coastal areas. The presence of such topography makes it more difficult and less feasible to operate tractors in these landscapes. The overall tractor density per thousand hectares of net sown area in India was 66 during 2021-22.

The relationship between tractor density and food-grains productivity in Indian states is shown in **Fig. 7**. The lines of average food-grain productivity (2.5 t/ha) and average tractor density (66 tractors/1000 ha) are superimposed on the **Fig. 7** by dividing the states into four categories. The four categories are high tractor density and high yield (A), low tractor density and high yield (B), high tractor density and low yield (C) and low tractor density and low yield (D). The states of Punjab, Haryana, Uttar Pradesh and Andhra Pradesh (including Telangana) represent the first category of high tractor density with high yield due to utilization of maximum tractor power to increase food-grains productivity. However, the states of West Bengal and Kerala represent the second category of low tractor density with high yield. This indicates that these states utilize more animate power sources than the tractor power. Tamil Nadu represents the national average tractor density with high food-grain production. Uttarakhand, Jharkhand

Fig. 6 State-wise tractor population and density



(KL-Kerala; AS-Assam; WB-West Bengal; HP-Himachal Pradesh; CG-Chhattisgarh; KA-Karnataka; MS-Maharashtra; RJ-Rajasthan; OR-Odisha; J&K-Jammu and Kashmir; MP-Madhya Pradesh; GJ-Gujarat; TN-Tamil Nadu; UK- Uttarakhand; AP+TG-Andhra Pradesh (including Telangana); UP-Uttar Pradesh; PB-Punjab, JH-Jharkhand; BR-Bihar; HR-Haryana)

Fig. 7 Tractor density and productivity in different states of India during 2021-22

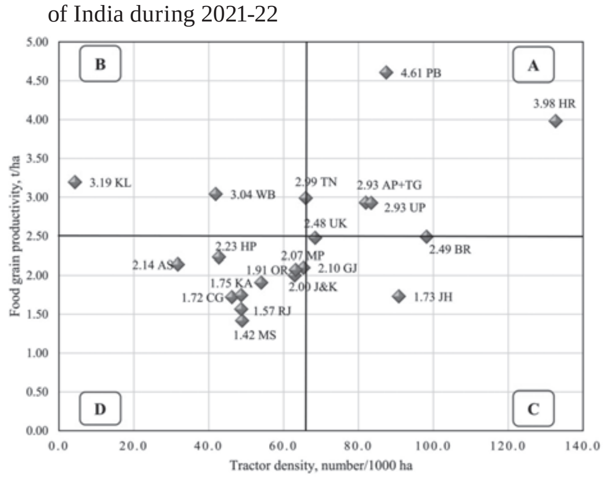


Table 5 Population, power and intensity of mechanical power sources

(Population, Million numbers; Power, Million kW; Intensity, No. per 1000 ha)

Year	Tractors			Power Tillers			Diesel Engines			Electric Motors		
	Population	Power	Intensity	Population	Power	Intensity	Population	Power	Intensity	Population	Power	Intensity
1971-72	0.168	4.38	1	0.016	0.09	0.10	1.443	8.08	10.00	1.535	5.679	10.00
1981-82	0.531	13.86	4	0.032	0.18	0.23	3.061	17.14	21.86	3.203	11.851	22.88
1991-92	1.192	31.11	8	0.060	0.02	0.42	4.800	26.88	33.57	6.019	22.270	42.09
2001-02	2.546	67.342	18	0.123	0.69	0.87	5.981	33.494	42.50	9.508	35.179	67.56
2011-12	4.843	126.40	34	0.308	1.72	2.18	7.430	51.598	52.69	13.945	51.596	98.90
2021-22	9.173	269.26	66	0.508	2.84	3.65	9.157	51.28	65.71	21.392	79.150	153.51

and Bihar states represent the third category of high tractor density and low yield. This may be because of small land holdings and tractor usage for non-agricultural purposes in these states. The remaining states i.e. Assam, Odisha, Chhattisgarh, Karnataka, Rajasthan, Maharashtra, Gujarat, Madhya Pradesh, Himachal Pradesh and Jammu and Kashmir fall under fourth category of low tractor density and low food-grain productivity. This may be due to low level of farm mechanization in these states. Madhya Pradesh, Maharashtra and Rajasthan states have high tractor population of 961,393, 822,691 and 864,891 units, respectively (**Fig. 6**) and have low tractor density due to higher cultivated area of 15.67, 20.51 and 20.87 million ha, respectively (Anonymous, 2019a).

2.2.4 Power Tiller

Power tiller population has increased exponentially at a CAGR of 7.16% from 0.016 million in 1971-72 to 0.508 million in 2021-22 (**Table 5**). The availability of power tillers per 10000 ha area has significantly increased from 1 in 1971-72 to 36.5 in 2021-22. The power available from power tiller for agricultural works has increased from 0.001 kW/ha (0.09 million kW) in 1971-72 to 0.02 kW/ha (2.84 million kW) in 2021-22 (**Tables 1** & **5**).

2.2.5 Diesel Engine

The population of diesel engine has increased at CAGR of 3.76% from 1.443 million in 1971-72 to 9.157 million in 2021-22 (**Table 5**). During 2021-22, the availability of diesel engines per 1000 ha area has increased to 66 from 10 in 1971-72. The power available from diesel engine for different stationary as well as mobile agricultural works has increased from 0.05 kW/ha (8.08 million kW) in 1971-72 to 0.37 kW/ha (51.28 million kW) in 2021-22 (**Table 1** & **5**).

2.2.6 Electric Motor

The population of electric motor has increased exponentially from 1.54 million in 1971-72 to 21.4 million in 2021-22 (**Table 5**). During 2021-22, the availability of electric motor per 1000 ha area has increased to 154 from 10 in 1971-72. The power available from electric motor for agricultural works has increased at 5.41% CAGR from 0.04 kW/ha (5.68 million kW) in 1971-72 to 0.57 kW/ha (79.15 million kW) in 2021-22 (**Tables 1** & **5**).

Farm Mechanization Status

Farm mechanization makes farmers daily life more comfortable by alleviating drudgery and labour requirement for farm operations. The countries which have higher level of farm mechanization are able to increase their production and are better equipped to meet their present and future demands (Tiwari et al., 2019). Shortage of farm labour and the need to enhance farm productivity are among the main reasons for increasing farm mechanization in India.

The mechanization levels for major food-grain crops in India i.e. rice, wheat, maize, sorghum & millets, pulses, oilseeds, cotton and sugarcane were assessed for different agricultural operations such as seed-bed preparation, sowing/planting/transplanting, weeding/interculture, plant protection, harvesting and threshing (**Table 6**). It indicates that wheat crop is highly mechanized (69%) as compared to other food-grain crops, whereas sorghum and millets are the least mechanized crops (33%). Amongst all the farm operations, seedbed preparation is the highly mechanized operation with 70% average mechanization level for all major crops whereas weeding, interculture and plant protection operations are the least mechanized with 32% average level of mechanization. In seedbed preparation, wheat and rice crops have higher mechanization levels of 85% and 80%, respectively than other crops. The mechanization level for the same operation in sorghum and millets (60%) is the least. The sowing operation has the highest mechanization level (65%) in wheat crop, while the mechanization level for planting/transplanting operation for sugarcane crop is only 25%. In case of harvesting and threshing operations, the mechanization levels for wheat and rice

Table 6 Mechanization levels for major crops in India during 2020-21

Crop	Seed-bed preparation	Sowing/ planting/ transplanting	Weeding and interculture& plant protection	Harvesting and threshing	Crop wise average
Rice	80	35	35	60	53
Wheat	85	65	50	75	69
Maize	70	45	40	30	46
Sorghum and millets	60	30	20	20	33
Pulses	65	40	25	35	41
Oilseed	65	40	20	30	39
Cotton	70	40	35	0	36
Sugarcane	65	25	30	20	35
Operation wise average	70	40	32	34	47

crops are more than 60% and there is no mechanization in cotton crop. The wheat, rice and maize are the highly mechanized crops with overall mechanization levels of 69, 53 and 46%, respectively and followed by pulses (41%), oil-seeds (39%), cotton (36%), sugarcane (35%) and sorghum and millets (33%). The overall farm mechanization levels for seedbed preparation, sowing/planting/transplanting, weeding/interculture/plant protection and harvesting and threshing operations are 70, 40, 32 and 34%, respectively. The overall farm mechanization level for major crops grown in the country is 47% which is lower than USA (95%), Europe (95%), Russia (85%), Brazil (75%) and China (60%) (Anonymous, 2018).

The penetration of micro-irrigation systems is still very low in India i.e. 9.9%, which is much lower as compared to countries like Israel, US and even China. Since 2005, area covered under micro-irrigation system has increased at a CAGR of 9.2% and reached to 13.78 million hectares during 2022 (**Fig. 8**).

The majority of area covered under micro-irrigation is under sprinkler irrigation with 7.1 Mha area and 6.32 Mha area under drip irrigation during 2020-21. The states with large area under micro-irrigation include Karnataka (2.09 Mha), Rajasthan (2.01 Mha), Maharashtra (1.92 Mha), Andhra Pradesh (1.90 Mha) and Gujarat (1.63 Mha) while the states of Meghalaya (615 ha), Jammu & Kashmir (2059 ha) and Tripura (2095 ha) have very low area under micro-irrigation (Fig. 9). The largest area covered under drip irrigation was reported in Andhra Pradesh (1.38 Mha) and followed by Maharashtra (1.35 Mha), Gujarat (0.86 Mha) and Tamil Nadu (0.8 Mha). However, the largest area covered under sprinkler irrigation was reported in Rajasthan (1.73 Mha) and followed by Karnataka (1.3 Mha), Gujarat (0.76 Mha) and Haryana (0.6 Mha) (**Fig. 9**). The low penetration of micro-irrigation system was observed in the north eastern states particularly hilly region of India due to terrace farming.

Farm Machinery Manufacturing and Sale

With the growing demand for pre-harvest and post-harvest machinery globally, India's export import trade of agro-machinery has more than doubled during the last 6 years. Exports of farm machinery are mainly driven by tractors, while imports are driven by farm machines other than tractors (**Figs. 10** & **11**). There are relatively more diversified export markets than import markets, but imports are mostly from China (**Fig. 12**). India mainly imports harrows, scarifiers, cultivators, weeders and hoes, harvesting and threshing machinery, other soil working machinery, lawn mowers etc. for use in agriculture, horticulture and forestry. The major share in import of farm machinery to India is of China (53%) and followed by Thailand (12.3%), Italy (8.4%), Japan (7.5%) and USA (4.8%). The remaining 14% is contributed by other countries (Anonymous, 2023).

4.1 Tractor

Tractor is the largest segment

Fig. 8 Trend of area covered under micro-irrigation in India

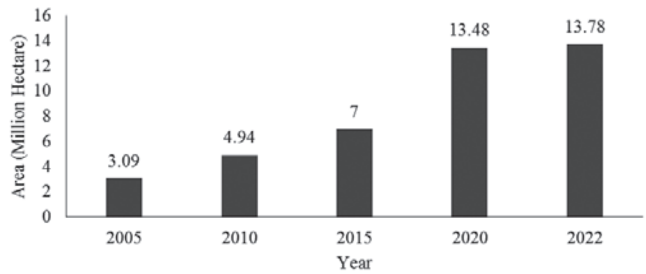
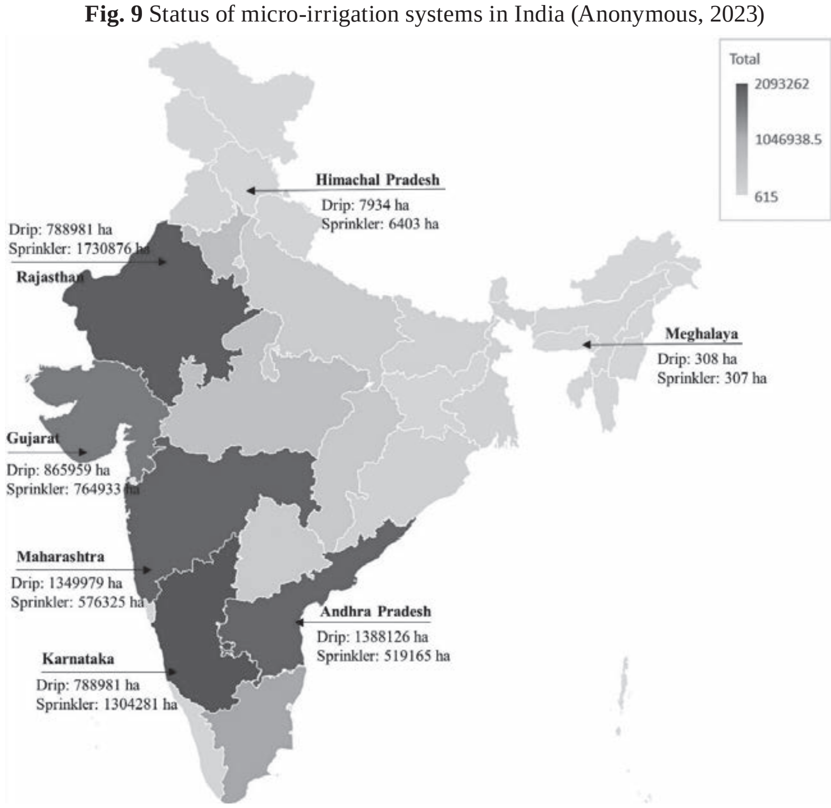


Fig. 9 Status of micro-irrigation systems in India (Anonymous, 2023)



in the farm machinery category with annual sale of about 800,000-850,000 units. The market has grown at a CAGR of 6.7% during last two decades. While the country produces large volume of tractors, it also exports tractors to other countries across the world. The primary countries for export of tractors include Asian and African countries where soil and agro-climatic conditions are similar to India.

The Indian tractor industry is relatively young but now has become the largest market worldwide accounting one third of the global production. The trend in production and sale of tractor in India is presented in **Fig. 13**. During 2021-22, 1,065,000 tractor units have been produced in India (**Fig. 13**). Mahindra and Mahindra Ltd., Mumbai with 39.6% market share in sale of tractors in India leads the domestic tractor market and followed by TAFE, Chennai (17.8%), International Tractors Ltd., Hoshiarpur (11.9%) and John Deere, Pune (10.2%). The export of tractors from India increased at a CAGR of 9% from 59,000 units in 2012-13 to 129,000 units in 2021-22. As per the report of Ministry of Commerce and Industry (GoI), export of tractors from India increased by more than 72% to USD 1025 million during April-December 2021 as compared to USD 594 million during April-December 2013.

The domestic sale of the tractors based on the power range is shown in **Fig. 14**. The sale of 23-30 kW tractors was the highest from 2001-02 to 2012-13, however, 31-37 kW power range tractors dominated the market afterwards. The share in sale of 31-37 kW tractors has increased from 17% to 54% during last two decades. It represents the increase use of high capacity machinery on custom hiring basis in India with high power tractors. However, during the same period, the share of 23-30 kW tractors decreased from 53% to 28% and the share of 15-22 kW tractors decreased from 22% to 7%. The share of less than 15 kW tractor was negligible (below 1%) up to 2007-08 and afterwards it increased to 3% in 2021-22. During last two decades, domestic sale of tractors is in increasing trend for high (31-37 kW) and low (≤ 15 kW) power ranges of tractors.

4.2 Power tiller

The current market for power tillers in India is estimated at 63,000 units during 2021-22. The market is dominated by VST Tillers Tractors Ltd. (Karnataka) and followed by Kirloskar Oil Engines Ltd. (Maharashtra) and Kerala Agro Machinery Corporation Ltd. (KAMCO) (Kerala). VST Tillers Tractors Ltd. is market leader in India with 58% share. The remaining market is catered by power tillers mainly imported from China. The domestic sale of power tiller is dominated by government-driven subsidy of Rs. 40,000-90,000 per power tiller. This subsidy includes Govt. of India (SMAM) share plus top up subsidy under state Govt. plans. Small farm sizes and high wages of farm labour create a huge opportunity for power tiller market in India.

4.3 Combine Harvester

Even though domestic companies

Fig. 10 Total farm machinery export (Anonymous, 2023)

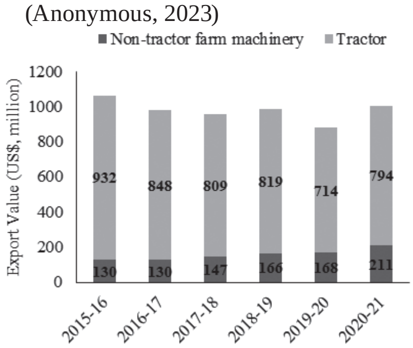


Fig. 11 Total farm machinery import (Anonymous, 2023)

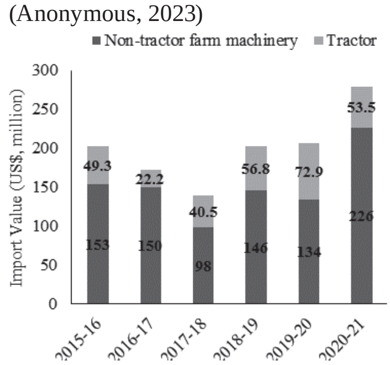


Fig. 12 Share of countries in export of non-tractor farm machinery from India (Anonymous, 2023)

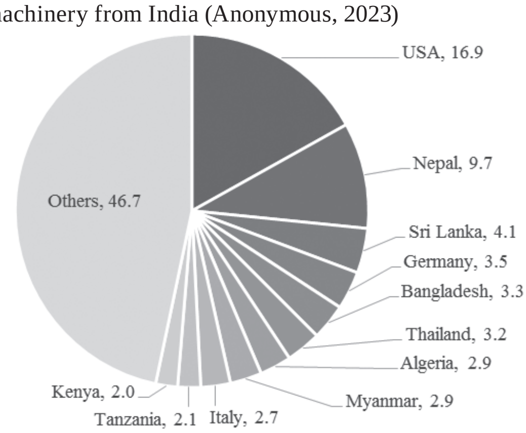
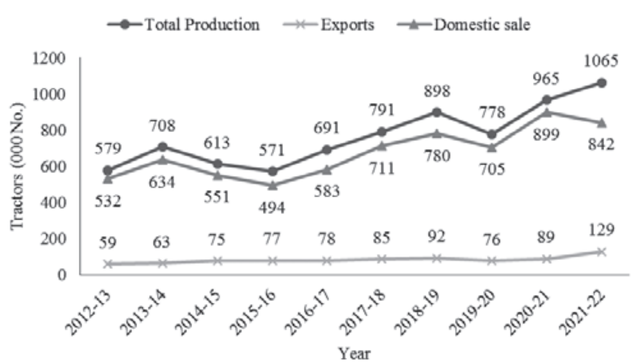


Fig. 13 Trend in production, domestic sale and export of tractors in India



take the major share of the market of combine harvester, foreign players are slowly becoming prominent (Anonymous, 2018). In 2013-14, India exported 730 units of combine harvester which has increased at a CAGR 11.89% to 1,280 during 2017-18 (**Fig. 15**). On other hand, import of combine harvester has increased at a CAGR of 45.24% from 950 units in 2013-14 to 6,140 units in 2017-18. Export value of combine harvesters increased from Rs. 416.5 million in 2016-17 to Rs. 545.9 million in 2017-18, while import has also increased from Rs. 683.1 million to Rs. 951.3 million. The export-import of combine harvesters indicated that India is a net importer of combine harvester. Some countries like Iran, Sri Lanka and Nepal generally import combine harvesters from India.

4.4 Water Lifting Devices

Water lifting devices are used to lift water from ground water sources or surface water sources. The ground water can be lifted by creating dug wells or tube wells, while the surface water can be stored in naturally created or constructed water bodies. The water lifting devices such as electric pump, diesel pump, solar pump, manual or animal operated equipment are used to lift water from these resources to irrigate the agricultural land.

The availability of water lifting devices in India during different periods is presented in the **Table 7**.

Table 7 Water lifting devices/energy sources used for minor irrigation schemes

(Values are in million numbers)

Year	Source of energy / Water lifting device					
	Electric Pumps	Diesel Pumps	Solar Pumps	Manual/ animal equipment	Others*	Total
1993-94	5.723	4.599	0.040	1.099	0.271	11.732
2000-01	10.271	6.551	0.011	1.602	0.675	19.110
2006-07	11.448	6.474	0.006	0.777	1.699	20.406
2013-14	14.090	4.924	0.003	0.282	1.463	20.762
2017-18	16.978	4.962	0.024	0.201	0.160	22.325

*Others include other energy sources, wind mill and schemes with more than one energy source

Sources: I, II, III, IV, V & VI minor irrigation census (GoI)

The number of water lifting devices increased at a CAGR of 2.7% from 11.73 million in 1993-94 to 22.32 million in 2017-18. The number of electric pumps increased from 5.72 million in 1993-94 to 17 million in 2017-18, while population of other sources of irrigation decreased during the same period. Electric pumps are mainly used in India for irrigating major crops (**Fig. 16**). Similarly, it indicates that the diesel pumps, solar pumps and manual/animal drawn equipment are being replaced

Fig. 14 Power-wise sale trend of tractors in India

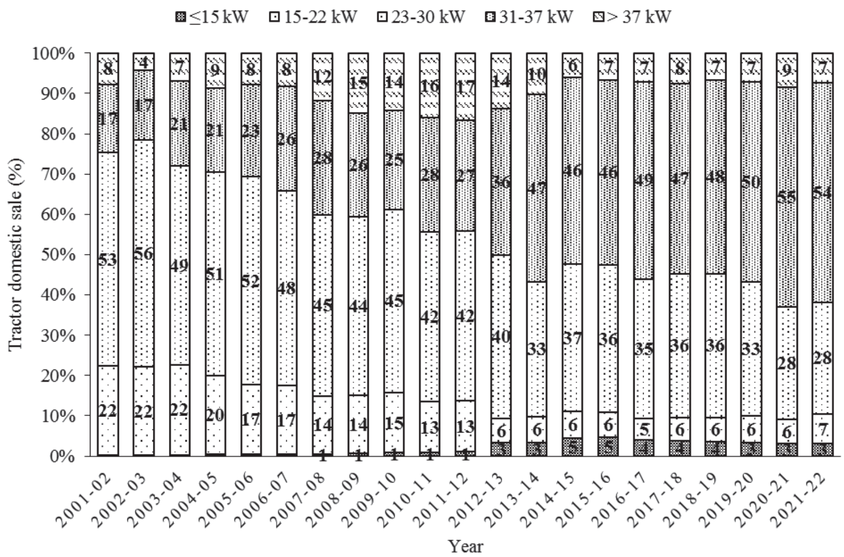


Fig. 15 Trend of export and import of combine harvester in India

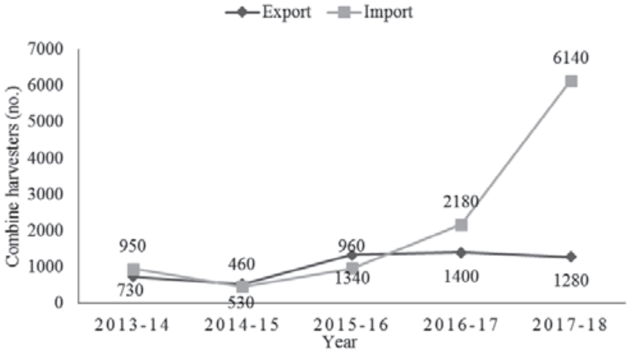
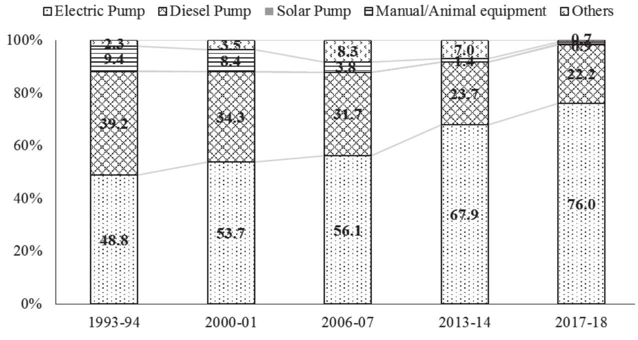


Fig. 16 Trend in use of power sources in minor irrigation schemes in India



by electric motor for water lifting purpose.

Schemes and Efforts of Government to Promote Mechanization

The Government of India has launched several schemes and policies to promote farm mechanization amongst the farmers. The Rashtriya Krishi Vikas Yojana (RKVY), the Sub-Mission on Agricultural Mechanization (SMAM), the Mission for Integrated Development of Horticulture and the National Food Security Mission, are some of the programmes that either entirely or partially promote farm mechanization. SMAM is the largest central government scheme under which subsidy is provided for the purchase of various types of agricultural implements and machinery used for tillage, sowing, planting, harvesting, threshing, plant protection, inter-cultivation and residue management. Along with the central government, state governments also provide subsidies on the purchase of farm machinery through their agricultural departments. The farm mechanization level in India is predicted to reach to 75% by 2047 from the present level of 47% with mutual efforts of government and other related stakeholders.

The Government of India has launched different schemes from time to time to promote micro-irrigation systems amongst the farming community. Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), Micro Irrigation Fund (MIF), National Mission on Micro-irrigation (NMMI), National Mission for Sustainable Agriculture (NMSA), etc. are some of the schemes. PMKSY provides subsidy @55% of the indicative unit cost to small and marginal farmers and @45% to other farmers for encouraging them to install drip and sprinkler irrigation systems with a tagline of "har khet ko pani" meaning assured irrigation to every farm. MIF helps the states to avail loan at lower interest rate for short period to implement micro-irrigation technologies to enhance water use efficiency. NMMI and NMSA were launched with a clear mission to promote micro-irrigation systems. The Gujarat Government and Gujarat Green Revolution Company Ltd, is a public private partnership model for the implementation of micro-irrigation system. Many such initiatives are being taken by various state governments.

To encourage the projects based on artificial intelligence (AI), blockchain, remote sensing, robots and drones, Government of India launched "Digital Agriculture Mission 2021-25". Along with this mission, to promote use of "Kisan drones" for crop assessment, digitization of land records, and spraying of pesticides and nutrients, government is providing financial assistance at the rate 100% of the cost of agriculture drone up to a maximum of Rs. 1.0 million per drone for purchase of drones to government institutes engaged in agricultural activities. There is also a provision of grants up to 75% of the cost of agriculture drone to the Farmers Producers Organizations (FPOs) for its demonstrations on the farmers' fields. To assist farmers in renting drones, Custom Hiring Centers (CHCs) under Cooperative Society of Farmers, FPOs?and Rural entrepreneurs are provided financial assistance at a rate of 40% (maximum Rs. 0.4 million) for purchase of drones. Agriculture graduates establishing CHCs are eligible to receive financial assistance at a rate of 50% of the cost of drone up to a maximum of Rs. 0.5 million per drone. For individual purchase of drones, the Small and Marginal, Scheduled Caste/Scheduled Tribe, Women and North Eastern State farmers are provided financial assistance @50% of the cost up to a maximum of Rs. 0.5 million and other farmers @40% up to a maximum of Rs. 0.4 million.

Impact of Farm Mechanization

Several studies have been attempted in different parts of India by various organizations and individuals to assess the impact of farm mechanization. The impact has been assessed in terms of agricultural inputs (seed, fertilizer, farm labor, fuel etc.), agricultural production and productivity, cropping intensity, employment generation etc. As a result of agricultural mechanization, various power sources, and improved farm tools and equipment are utilized to reduce the work of humans and draught animals to increase cropping intensity, precision and timelines of utilization of various inputs, and to reduce losses at different stages of crop production. Ultimately, farm mechanization should improve production and productivity while reducing cost.

The seedbed preparation, seed and fertilizer placement, weed control, intercultural operation, harvesting and threshing operations are performed on time due to the farm mechanization which increases the quality of operation. According to household survey under SMAM, 1.9-20.8% reduction in seed rate, 11.2-21.1% reduction in fertilizer, 23.7-40.1% reduction in labor cost and 20.4-39.7% reduction in time of operation were reported due to use of improved farm machinery. These all factors contributed to increase of crop yield by 14.2-25.7% with reduced post-harvest losses (Anonymous, 2020b). Along with reduction in inputs, the use of power weeder, cono-weeder, garden tillers and other improved tools has impacted in reduction of weeds in the range of 20.9 - 45% and resulted into higher yield. However, the use of multi-crop planters or improved seed drills improved seed germination rate in the range of 7.7-32.3%.

Hence, the crop yield has been enhanced with reduction in seed rate.

Cropping intensity was dependent on the available farm power and water availability. It increased by 156 and 165% for tractor using and tractor owning farms, respectively (Ramya et al., 2016). Furthermore, the facilities of canals, tube well irrigation and micro-irrigation increased the percent gross cropped area as well as the crop productivity (Prajapat et al., 2022). Thus, the states like Punjab, Haryana, Uttar Pradesh having high power availability and higher irrigated area also had higher grain yield per hectare.

Agricultural mechanization increased the overall employment of human labour due to multiple cropping, increase intensity of cultivation and higher production. Some studies also reported that mechanization increased the demand for hired labour. Rajkhowa et al. (2021) reported that the unit increase in the level of farm mechanization increases the demand for hired labour by 12%. The farm mechanization also has a positive effect on women's participation in farm work. Furthermore, mechanization tend to increase employment for on-farm as well as off-farm activities as a result of manufacturing, repair, servicing and sale of tractors and improved farm equipment. On the contrary, the farm mechanization decreases the demand of hired labour with the increase of farm size (Rajkhowa et al., 2021).

Agricultural mechanization also significantly helped the farming community in the overall economic upliftment. The gross income per hectare was reported to be about 63% higher for tractor owning farms as compared to bullock farms (Ramya et al., 2016). Furthermore, farm mechanization increased agricultural productivity and profitability on account of timeliness of operations, better quality of work and more efficient utilization of crop inputs. Undoubtedly, farm mechanization displaced animate power from 60 to 95% and resulted in reducing time requirement for quality farm work.

Way Forward in Farm Mechanization

Mechanization of small and non-contiguous group of small farms in India is against 'economies of scale' and need land consolidation by sale, lease or contract. High capacity machines for the farming operation through custom hiring or contractual farming is the characteristics of today's Indian agriculture. It needs promotion by an app-based farmer-to-farmer aggregation platform, which bridges the demand and supply gap of machinery or equipment by connecting owners of tractors and farming equipment with those who require their services (Mehta et al., 2020).

Mechanization of rice, sugarcane, cotton, potato and horticultural crops, greenhouse/polyhouse cultivation and vertical farming are areas that need more attention. High potential of vegetables, fruits and flowers cultivation in the hill region of the country demands for appropriate technologies for mechanization of hill agriculture. The increased participation of female workers demands for gender-neutral mechanization of farm operations. Conservation agriculture, organic farming, natural farming and precision farming are the new areas of Indian agriculture which need more attention for mechanization.

Precision agriculture using GIS/GPS techniques, controlled precision application of water through drip and sprinkler irrigation systems, multi-functional farm equipment to conserve energy and to control traffic in the field, integrated crop and energy management, application of renewable energy sources such as solar based equipment, biofuels and plant oils for motive and tractive power, occupational health hazards and safety on the farm are some of the areas that need more attention at present.

The modern technologies such as sensors, hyper spectral imaging, remote sensing, drones, robots and artificial intelligence, etc. are now being used in agriculture and are the future of Indian agriculture. Site-specific management of the inputs in agriculture farm through sensor-based systems, AI and farm management practices are the need of hour. Sensors will be used in many areas such as determining soil moisture and nutrient assessment which help farmer in efficient chemicals/fertilizers application. AI and IoT based smart irrigation and fertigation systems will be used for field and horticultural crops to enhance water and nutrient use efficiency. Application of drones in agriculture will be for spraying, fertilizer application, crop health monitoring, yield estimation and crop management. The drudgery prone and repetitive farm operations such as weeding, spraying and harvesting of costly fruits and vegetables need to be enabled with robotics and AI leading to improved accuracy and productivity (Mehta et al., 2020).

Increased population, increased food demand, reduced acreage and labour under agriculture and food wastage during production and transport are having a major impact in Indian agriculture. The increasing role of technology in agriculture to address these issues is the only way forward to a food-secure future. Technology in agriculture has the potential to lead India to be "Atmanirbhar" in all respects.

Conclusions

Agricultural mechanization in India increased significantly during last two decades. The use of electro-mechanical power over animate power has increased at a fast pace for different agricultural operations on farm. The share of animate power sources in total farm power availability has reduced from 69% in 1971-72 to 5.16% in 2021-22. The power available from agricultural workers and draught animals was 0.082 and 0.07 kW/ha, respectively, while, power available from electro-mechanical power sources such as tractors, power tillers, diesel engines and electric motors was 1.93, 0.02, 0.36 and 0.57 kW/ha, respectively in 2021-22. The overall farm power availability (FPA) in India increased from 0.37 kW/ha in 1971-72 to 3.04 kW/ha in 2021-22. Punjab, Haryana and Bihar are the states having higher power availability for farm operations, whereas, the north eastern and eastern states have lower farm power availability. This region of India needs a special focus to increase FPA as well as region specific mechanization. Despite of the overall farm mechanization level of 47%, Indian farmers adopted improved farm machinery for seed-bed preparation, sowing/planting/transplanting, plant protection, irrigation, harvesting and threshing operations. Also, the average FPA needs to be increased from 3.04 kW/ha to 7.50 kW/ha by 2047 to increase farm mechanization level to 75%.

The present trend in agriculture is towards the use of high capacity farm machinery on custom hiring or contractual farming. Organic farming, conservation agriculture and precision agriculture are the new emerging areas and need more focus to develop energy efficient, cost effective and reliable advanced agricultural implements and machinery. The enhancement in the productivity and sustainability in agriculture needs adoption of new age tools i.e. sensors, AI, IoT, drones and robots.

REFERENCES

Anonymous. 2001. Report on Census of Minor Irrigation Schemes 1993-94 Part-I. Ministry of Water Resources Minor Irrigation Division, Government of India. https://micensus.gov.in/sites/default/files/Second-MI-report-I_2.pdf

Anonymous. 2005. Report on 3rd Census of Minor Irrigation Schemes 2000-01. Ministry of Water Resources Minor Irrigation Division, Government of India. https://micensus.gov.in/sites/default/files/Third-MI-report.pdf

Anonymous. 2013. Fifteenth Indian Census 2011. Government of India. https://censusindia.gov.in/census.website/

Anonymous. 2014. Report on 4th Census of Minor Irrigation Schemes 2006-07. Ministry of Water Resources Minor Irrigation Division, Government of India. https://micensus.gov.in/sites/default/files/4thmicensusreport.pdf

Anonymous. 2017a. Report on 5th Census of Minor Irrigation Schemes 2013-14. Ministry of Water Resources Minor Irrigation Division, Government of India. https://micensus.gov.in/sites/default/files/5th-MICensusReport.pdf

Anonymous. 2017b. Agricultural Research Data Book (ARDB). ICAR-Indian Agricultural Statistics Research Institute (IASRI), New Delhi. http://apps.iasri.res.in/agridata/22data/HOME.HTML

Anonymous. 2018. Sectoral Paper on Farm Mechanization. Farm Sector Policy Department, National Bank for Agriculture and Rural Development. https://www.nabard.org/auth/writereaddata/file/NSP%20Farm%20Mechanisation.pdf

Anonymous. 2019a. Agricultural Census 2015-16 (Phase I). Department of Agriculture, Cooperation & Farmers welfare, Government of India. https://agcensus.nic.in/document/agcen1516/T1_ac_2015_16.pdf

Anonymous. 2019b. Farm Mechanization: Ensuring a Sustainable Rise in Farm Productivity and Income. FICCI & PwC. https://ficci.in/spdocument/23154/Online_Farm-mechanization-ficci.pdf

Anonymous. 2020a. 20th Livestock Census-2019 All India Report. Ministry of Agriculture Department of Animal Husbandry, Dairying and Fisheries, Krishi Bhawan, New Delhi. https://dahd.nic.in/documents/statistics/livestock-census

Anonymous. 2020b. Final Report for Impact Evaluation of Sub-Mission on Agricultural Mechanization. Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India. WAPCOS Limited. 564345/2020/O/O ADC(M&T), 502-740.

Anonymous. 2021. Agricultural Engineering Data Book. ICAR - Central Institute of Agricultural Engineering. https://ciae.icar.gov.in/publications/books.

Anonymous. 2022. Agricultural Statistics at a Glance 2021. Department of Agriculture & Farmers Welfare, Directorate of Economics & Statistics, Ministry of Agriculture & Farmers Welfare, Government of India. https://eands.dacnet.nic.in/PDF/Agricultural%20Statistics%20at%20a%20Glance%20-%202021%20(English%20version).pdf

Anonymous. 2023. Making India: A Global Power House in the Farm Machinery Industry. National Council of Applied Economic Research (NCAER), Report No. 20230101. https://www.ncaer.org/publication/making-india-a-global-power-house-in-the-farm-machinery-industry

Aryal, J. P., D. B.Rahut, G. Thapa, and F. Simtowe. 2021. "Mechanization of Small-Scale farms in South Asia: Empirical evidence derived from farm households survey". Technology in Society, 65: 1-14.

Chand, R. and J. Singh. 2022. Workforce Changes and Employment: some findings from PLFS Data Series. NITI Aayog Discus-

sion Paper 1/2022, NITI Aayog, Government of India.
Maan, J. S. and P. Chaudhry. 2019. People and Protected Areas: Some Issues from India. Animal Biodiversity and Conservation, 42(1): 79-90.
Mehta, C. R., N. S. Chandel and T. Senthilkumar. 2014. Status, challenges and strategies for farm mechanization in India. Agricultural Mechanization in Asia Africa and Latin America. 45(4): 43-50.
Mehta, C. R., N. S. Chandel, P. C. Jena and Anamika Jha. 2019. Indian Agriculture counting on Farm Mechanization. Agricultural Mechanization in Asia, Africa & Latin America. 50(1): 84-89.
Mehta, C. R., N. S. Chandel and Y. A. Rajwade. 2020. Smart farm mechanization for sustainable Indian agriculture. Agricultural Mechanization in Asia, Africa and Latin America (AMA), 51(4): 99-105, 95.
Prajapat, R., V. Yogi, N. K. Pareek and S. Sharma. 2022. Impact of growth of groundwater irrigated area on cropping intensity and crop productivity in Bikaner district of Rajasthan. Journal of Soil and Water Conservation. 21. 154-159. 10.5958/2455-7145.2022.00026.1.
Rajkhowa, P. and Z. Kubik. 2021. Revisiting the relationship between farm mechanization and labour requirement in India. Ind. Econ. Rev. 56, 487-513. https://doi.org/10.1007/s41775-021-00120-x
Ramya, P. and V. Muruganandham. 2016. Impact of agricultural mechanization on production, productivity and employment of labour. Shanlax International Journal of Commerce, 4(3).
Tiwari, P. S., K. K. Singh, R. K. Sahni and V. Kumar. 2019. Farm mechanization – trends and policy for its promotion in India. Indian Journal of Agricultural Sciences. 89(10): 1555-62.

■■

◇◇

ABSTRACTS

The ABSTRACTS pages is to introduce the abstracts of the article which cannot be published in whole contents owing to the limited publication space and so many contributions to AMA. The readers who wish to know the contents of the article more in detail are kindly requested to contact the authors.

2231

Effects of LEDs on The Physical and Biochemical Properties of in *vitro* Seedlings of *Nicotiana tabacum* L.: T. Demirci (Corresponding author: tunhandemirci@sdu.edu.tr), Ö. Uysal, K. Ekinci1, N. Göktürk Baydar

In this study, it was determined that the effects of light quality on some physical and biochemical properties of in *vitro* seedlings of tobacco (*Nicotiana tabacum* L.). For this purpose, tobacco seedlings were cultures under red (R) LED light, blue (B) LED light, red-blue (RB) LED light (6:4), blue-red (BR) LED light (6:4) and cool white (W) LED light (as a control) for 28 days in in *vitro* conditions. After that seedlings were evaluated in terms of shoot length, shoot weight, leaf number, total chlorophyll, total phenolic, and nicotine amounts. It was determined that the greatest shoot length was obtained with R LED light while the lowest value was detected in seedlings under RB LED light. The plants under W LED light had higher shoot weight than the others. In terms of leaf number, there was no significant differences among the plants treated with R, W and BR LED lights. However the lowest leaf number was found in the plants treated with B LED light. The total amount of chlorophyll reaching the highest level with RB LED light, measured at the lowest level with B LED light. The highest total phenolic content was detected as 8.82 mg g^{-1} with BR LED light. On the other hand, the lowest total phenolic content (6.02 mg g^{-1}) was obtained from the plants treated with R LED light. The greatest value in nicotine amount as well as in total phenolic amount was obtained with BR LED lights 0.31%. As a conclusion, LEDs at different quality significantly affected growth, chlorophyll, total phenolic and nicotine contents of in *vitro* tobacco seedlings. These results demonstrated that different quality of LED lighting can be used to enhance the physical and biochemical properties of plants.

Co-operating Editors

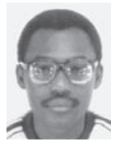

B Kayombo

M F Fonteh

S A Ndindeng

S E Abdallah

A A K El Behery

Ahmad Addo

R J Bani

I K Djokoto

A N GITAU

D K Some


K Houmy

A F Alonge

O A Oy-elade

Umar B Bindir

J C Igbeka

E U-Odigboh

K C Oni

U L Opara

N G Kuyembeh

A H Abdoun


A B Saeed

A I Khatibu

S Tembo

H A Cetrangolo

I de A Nääs

A E Ghaly

E J Hetz

M A L Roudergue

R Aguirre

O Ulloa-Torres


Y M Mesa


P P Rondon


S G C Magaña


H Ortiz-Laurel


A I Luna Maldonado


G C Bora


M R Goyal


A K Mahapatra


Daulat Hussain


M A Mazed


R Ali


Kinga Norbu


M A Basunia


Minzan Li


Xiwen Luo


S M Ilyas

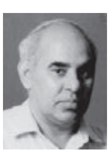

Surya Nath


Indra Mani


C R Mehta


B S Pathak


V M Salokhe


G Singh


P Soni


R Yadav


Kamaruddin Abdullah


M Behroozi-Lar


Saeid Minaei


A Mahdavian


V R Sharabiani


A M Abdul-Munaim


H Hasegawa


B A Snobar


J H Chung


In-Bok Lee


M Z Bardaie


Enkhbayar Gonchigdorj


M P Pariyar


H P W Jayasuriya


Alamgir A Khan


A Q A Mughal


M S Mirjat


N A Abu-Khalaf


R M Lantin


R P Venturina


S A Al-Suhaibani


A M S Al-Amri


S G Illangantileke

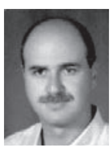

Suming Chen


S Krishnasreni


S Phong-supasamit


A Senanarong


C Ertekin


I Haffar


N Hay


P V Lang


T H Katardjiev


P Kic


J Müller


K P Ferentinos


Nick Sigrimis


E Gasparetto


Y Lobachevsky


M Martinov


J Ortiz-Cañavate


Brian G Sims

-EUROPE-

Tihomir Hristov Katardjiev
General Manager at Yogurtson Trade Ltd., Omachi 216-74, Ichikawa-shi, Chiba-ken 272-0801, Japan (BULGARIA). miro@yogurtson.com

Pavel Kic
Professor, Czech Univ. of Life Sciences Prague, Faculty of Eng. 16521 Prague 6-Suchdol, CZECH REPUBLIC. TEL+420-2-2438314 kic@tf.czu.cz

Joachim Müller
Prof. of the Univ. Hohenheim, Institute of Agril. Eng., Head of Agric.l Eng. in the Tropics and Subtropics, Univ. of Hohenheim, 70593 Stuttgart, GERMANY. TEL+49-711-459-22490, Joachim.mueller@uni-hohenheim.de

Konstantinos P. Ferentinos
Researcher, Dept. of Agricultural Engineering, Institute of Soil & Water Resources, Hellenic Agricultural Organization "Demeter", Ministry of Agriculture and Food of Greece, 61 Dimokratias Av., Athens 13561, GREECE. kpf3@cornell.edu

Nick Sigrimis
Prof., Agricultural University of Athens, Iera Odos 75, Athina 118 55, GREECE. TEL +30-6940940885, ns@aua.gr

Ettore Gasparetto
Via Galileo Galilei 17, I-35121 Padova, ITALY. TEL +39-0250316619, ettore.gasparetto@unimi.it

Yakov Lobachevsky
Deputy Director of VIM, Federal State Budgetary Science Institution "Federal State Agro Engineering Center VIM", 1st Institutskiy passage, 5., Moscow -109428, RUSSIA. lobachevsky@yandex.ru

Milan Martinov
Prof., Faculty of Technical Sciences, Chair for Biosystems Eng., Novi Sad, SERBIA. TEL+ 381-21-485-2369, MilanMartinov@uns.ac.rs

Jaime Ortiz-Cañavate Puig-Mauri
Dpto. Ingenieria Rural Universidad Politécnica de Madrid, Esc. T. S. Ing. Agrónomos 28040-Madrid SPAIN. TEL+34-91-336-5852, jaime.ortizcanavate@upm.es

Brian G. Sims
FAO Agricultural Mechanization Consultant. 3 Bourneside Bedford MK41 7EG, U.K. sims.brian2@gmail.com

Retired Co-operating editors

Name	Nationality	Inaugural year	Retired year
Adrian Moens	Netherlands	1972	1989
Bala Krishna Shrestha	Nepal	1972	1991
A. M. Michael	India	1972	2022
Chul Choo Lee	Korea	1972	2014
Chau Van Khe	Vietnam	1972	1980
Manbahadur Gurung	Bhutan	1972	2006
Merle L. Esmay	U. S. A.	1972	1990
Giuseppe Pellizzi	Italy	1973	2012
Mohamed A. Bedri	Sudan	1973	1987
Shahansha-Uddin Choudhury	Bangladesh	1973	1991
T. B. Muckle	U. K.	1973	1978
Chang Joo Chung	Korea	1975	2014
T. Touggaard Pedersen	Denmark	1975	1990
Bilash Kanti Bala	Bangladesh	1976	1982
George B. Hanna	Egypt	1976	1988
Jun Sakai	Japan	1976	2015
Siswadhi Soepardjo	Indonesia	1976	1985
Tieng-Song Peng Taiwan	Taiwan	1976	2015
Mohammad Ilyas	Pakistan	1977	1981
Amala Prasad Sharma	Fiji	1978	1981
Arumugam Kandiah	Ethiopia	1978	1989
Bherulal T. Devrajani	Pakistan	1978	2004
John Kilgour	U.K.	1978	2014
Satish Chandra	Fiji	1979	1990
Jitendra P. Mittal	Nigeria	1980	1993
Naresh Chandra Saxena	India	1980	1988
Paris Andereou	Lebanon	1980	1984
Wang Wanjun	China	1981	2012
Allah Ditta Chaudhry	Pakistan	1981	2015
Allan L. Phillips	U. S. A.	1981	2004
Julien G. Van Lancker	Brundi	1981	1989
Suppiah Kathirkamathamby	Sri Lanka	1981	1991
Armed Hossain Mirdha	Mexico	1982	1991

Name	Nationality	Inaugural year	Retired year
A. A. Valenzuela	Chile	1982	2013
David Boakye Ampratwum	Ghana	1982	2011
Kshirode Chandra Roy	Bangladesh	1982	1985
M. H. Abdel Aziz	Saudi Arabia	1982	1991
Krishna Prakash Srivastava	Ethiopia	1983	1989
Muhammad Siddique Chaudhry	U. S. A.	1983	1991
Wimala Tissa Weerakoon	Zambia	1983	1985
Harry D. Henderson	Lebanon	1984	1985
Mohammad Afzal	Pakistan	1984	1994
A. P. Kaloyanov	Bulgaria	1985	2013
Soedjatmiko	Indonesia	1986	2014
Aalbert Anne Wanders	Netherlands	1988	2007
Ali Mahmoud El Hossary	Egypt	1988	2010
Chanchai Rojanasaroj	Thailand	1988	2011
Edward A. Baryeh	Zimbabwe	1988	2014
T. P. Ojha	India	1988	2015
Eltag S. Eldin Mahmoud	Sudan	1990	2011
Henrik Have	Denmark	1990	2009
Graeme Ross Quick	Australia	1995	2015
Rafiq ur Rehman	Pakistan	1995	2015
Abdulsamad Abdulmalik Hazza'a	Yemen	1999	2014
Yunus Pinar	Turkey	1983	2016
William J. Chancellor	U.S.A	1972	2017
Kunihiro Tokida	Japan	2016	2017
Shujun Li	China	2012	2018
S. F. (Sen-Fuh) Chang	Taiwan	1987	2018
Jan Pawlak	Poland	2002	2019
Oleg S. Marchenko	Russia	2003	2019
W. B. Hoogmoed	Netherlands	2007	2019
Sitaram Dagdupant Kulkarni	India	2017	2020
Shah M. Farouk	Bangladesh	1982	2021
S. R. Verma	India	1982	2021
Chetem Wangchen	Bhutan	2006	2022

Back Issues

AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

(Vol.52, No.2, Spring, 2021-)

◇ ◇ ◇

◇ ◇ ◇

Vol.53, No.3, Summer 2022

◇ ◇ ◇

Vol.53, No.4, Autumn 2022

◇ ◇ ◇

Vol.54, No.1, Winter 2023

INSTRUCTIONS TO AMA CONTRIBUTORS

The Editorial Staff of the AMA requests of articles for publication to observe the following editorial policy and guidelines in order to improve communication and to facilitate the editorial process:

Criteria for Article Selection

Priority in the selection of article for publication is given to those that –

a. are written in the English language;
b. are relevant: to the promotion of agricultural mechanization, particularly for the developing countries;
c. have not been previously published elsewhere, or, if previously published are supported by a copyright permission;
d. deal with practical and adoptable innovations by, small farmers with a minimum of complicated formulas, theories and schematic diagrams;
e. have a 50 to 100-word abstract, preferably preceding the main body of the article;
f. are printed, double-spaced, under 3,000 words (approximately equivalent to 6 pages of AMA-size paper) ; and those that
g. art: supported by authentic sources, reference or bibliography.
h. written in MS DOS format.

Rejected/Accepted Articles

a. As a rule, articles that are not chosen for AMA publication are not returned. At the earliest time possible, the writer(s) is advised whether the article is rejected or accepted.
b. When an article is accepted but requires revision/modification, the details will be indicated in the return reply from the AMA Chief Editor in which case such revision/modification must be completed and returned to AMA within three months from the date of receipt from the Editorial Staff.
c. The AMA does not pay for articles published.
d. Complimentary copies: Following the publishing, three successive issue are sent to the author(s).

Procedure

a. Articles for publication (original and one-copy) must be sent to AMA through the Co-operating Editor in the country where the article originates. (Please refer to the names and addresses of Co-operating Editors in any issue of the AMA). However, in the absence of any Co-operating Editor, the article needs to be sent to Co-operating Editor in the writer's neighboring country. Please note that it is AMA Chief Editor that decide whether publish each submitted paper on AMA or not. Even if Co-operating Editor found your manuscript suitable for publication on AMA, it can not the case with AMA Chief Editor.
b. Contributors of articles for the AMA for the first time are required to attach a passport size ID photograph (black and white print preferred) to the article. The same applies to those who have contributed articles three years earlier. In either case, ID photographs taken within the last 6 months are preferred.
c. The article must bear the writer(s) name, title/designation, office/organization, nationality and complete mailing address.

Format/Style Guidance

a. Article must be sent by E-mail with Word File and PDF File attached.
b. The data for graphs and photographs must be saved into piecemeal data and enclosed (attached) with the article.
c. Whether the article is a technical or popular contribution, lecture, research result, thesis or special report, the format must contain the following features:
   (i) brief and appropriate title;
   (ii) the writer(s) name, designation/title, office/organization; and mailing address;
   (iii) an abstract following ii) above;
   (iv) body proper (text/discussion);
   (v) conclusion/recommendation; and a
   (vi) bibliography
d. Tables, graphs and diagrams must be numbered. Table numbers must precede table titles, e.g., "Table 1 Rate of Seeding per Hectare". Such table number and title must be typed at the top center of the table. On the other hand, graphs, diagrams, maps and photographs are considered figures in which case the captions must be indicated below the figure and preceded by number, e.g., "Fig. 1 View of the Farm Buildings".
e. Papers are printed in black and white. Tables and figures must be made so as to be clearly understood in black and white.
f. **The data for the graph must also be included. (e.g. EXCEL for Windows)**
g. Tables and figures must be preceded by texts or discussions. Inclusion of such tables and figures not otherwise referred to in the text/discussion must be avoided.
h. Tables must be typed clearly without vertical lines or partitions. Horizontal lines must be drawn only to contain the sub-title heads of columns and at the bottom of the table.
i. Express measurements in the metric system and crop yields in metric tons per hectare (t/ha) and smaller units in kilogram or gram (kg/plot or g/row).
j. Indicate by footnotes or legends any abbreviations or symbols used in tables or figures.
k. Convert national currencies **in US dollars** and use the later consistently.
l. Round off numbers, if possible, to one or two decimal units, e.g., 45.5 kg/ha instead of 45.4762 kg/ha.
m. When numbers must start a sentence, such numbers must be written in words, e.g., Forty-five workers..., or Five tractors..."instead of 45 workers..., or, 5 tractors.

SUBSCRIPTION/ORDER FORM

AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA (AMA)

Issued Quarterly

AMA has Achieved an IMPACT FACTOR!!

AMA has been read by those involved in agricultural machinery and industry all over the world since the first publishment in 1971. Thanks to many contributions from both the readers and writers, in 2012, we have achieved an Impact Factor, established by Thomson Reuters in U.S.A. AMA is the only Japanese agricultural machinery and industry related magazine which achieved an Impact Factor.

Subscription Rate (includes surface mail postage)

Annual (4 issues)........................... ¥8,000
Single copy....................................... ¥2,500

(Check one)
☐ Please send me/us an invoice
☐ I/We enclose remittance for ¥ ___________
☐ Please charge my/our credit card
☐ VISA
☐ MASTER Card. No. ______________________

Exp. date ______________________

Signature ______________________

We deeply appreciate your payment by credit card (NO EXTRA CHARGE NEEDED).
We charge you extra 4,000 JPY when paid by check or wire transfer.

****

Name: ____

Firm: ____

Position: ____

Address: ____
(block letters)

FARM MACHINERY INDUSTRIAL RESEARCH CORP.
1-2-5, Kanda Jimbo-cho, Chiyoda-ku, Tokyo 101-0051, Japan
Tel. +81-3-3291-3674, Fax. +81-3-3291-5717
URL: http://www.shin-norin.co.jp
E-Mail: ama@shin-norin.co.jp


MOROOKA TECHNOLOGY to WORLDWIDE JOBSITE
HST SYSTEM AND RUBBER CRAWLER
MOROOKA developed Rubber Crawler about 40 years ago with joint development with Bridgestone. Rubber Crawler provides high performance even on irregular ground, stable moving on the sloping ground or snowy land.
Team MOROOKA Helps You ! Here's Experts in Each Field !!
Best Buddy in Muddy Fields
Tough and stable Rubber Crawler Forklift
Powerful and Invinsible Hero
Carrier Dump for a large amount
For fertilizer transportation
For sugar cane plant transportation
For potato transportation
Specialties of MOROOKA Products
Pioneer of the rubber crawler
● Seamless and durable rubber crawler assures high performance movement with low ground pressure.
● Simple and compact design allows easy operation for everybody.
● Ship structure underbody and rotary bogie system absorb the impact and allow the stable movement.
● Rubber crawler is used as base body of wide range of industrial machines.
● Rubber crawler and HST (hydrostatic transmission) system enables easy control for smooth & stable movement and huge driving power.
For forestry
For agriculture and multipurpose
ROTARY SCREEN
FORWARDER
MOBILE WOOD CRUSHER
FORKLIFT
SHOVEL LOADER
CARRIER
MOROOKA
MOROOKA Co., Ltd.
358, Shoubeeshindenmachi, Ryugasaki city, Ibaraki Prefecture, 301-0031, Japan
TEL : +81-297-66-2111 FAX : +81-297-66-3110 E-mail : info@morooka.co.jp
URL : www.morooka.co.jp (Japanese) www.morooka.com (English)