Automating Potato Cultivation: A Study of Single Row Planter

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Abstract:

This research paper focuses on the development and evaluation of a single row automatic potato planter designed for mini tractors to enhance potato cultivation and productivity in India. The study addresses the challenges faced in potato farming, such as labor-intensive practices and limited mechanization. The planter's key components, including the seed box, power transmission system, seed metering mechanism, ridger, and frame, are meticulously designed for efficient and precise potato sowing.

Performance evaluation of the planter was conducted through field tests, considering varying speeds and depths of sowing. Three dependent parameters were analyzed: Effective Field Capacity, Field Efficiency, and Missing Seed Percentage. Results showed that higher speeds increased effective field capacity, while deeper depths decreased it. The most efficient speed was found to be 1.25 km/hr, suitable for mini tractors. Missing seed percentage increased with higher speeds and depths due to chain velocity.

The study demonstrates the planter's potential to optimize potato planting operations, reduce labor intensity, and increase overall productivity. The findings provide valuable insights for farmers, policymakers, and stakeholders, encouraging the adoption of mechanized solutions to enhance vegetable production and achieve food and nutritional security in India. The single row automatic potato planter offers a practical and efficient tool for sustainable agriculture, contributing to India's agricultural prosperity and economic growth.

Keywords: Potato planter, Mini tractors, Potato cultivation, Agricultural productivity, Mechanized farming

1. INTRODUCTION:

Fruits and vegetables play a vital role in ensuring food and nutritional security for a vast population, and the consumption patterns in India have been shifting towards high-value foods, including fruits and vegetables, meat, dairy, and fish (Gulati et al., 2007). Among these, vegetable production has witnessed significant growth in India, with an impressive increase in production from 28.36 million tonnes in 1969-70 to 72.83 million tonnes in 1997-98. Presently, India produces around 113.5 million tons of vegetables across 7.2 million hectares, with an average productivity of 15.7 tonnes/hectare (Carneiro *et al*.,2013). Alongside the demand for local consumption, there has been a surge in the demand for vegetable exports, highlighting their potential as valuable commodities in international trade.

In the context of nutritional requirements, there has been a rise in the per capita consumption of vegetables in India from 95 grams to 175 grams per day (Sikorski et al., 2022). However, this still falls short of the recommended nutritional requirement of 285 grams per capita per day for a balanced diet. Vegetables are not only rich in essential nutrients but also contain phytochemicals with anti-cancerous and anti-inflammatory properties, conferring numerous health benefits to consumers. Potato (Solanum tuberosum), often referred to as the "King of Vegetables," holds great significance in the Indian vegetable basket. As a short-duration crop, potato yields more dry, edible energy and protein in a shorter time compared to cereals like rice and wheat. Thus, it emerges as a potential tool to achieve nutritional security in the nation. In spite of the growing importance of vegetables, the productivity and quality of vegetable crops in India face challenges due to the lack of technological interventions. Vegetable farming heavily relies on labor-intensive practices, and the limited mechanization further restricts the expansion of both the cultivation area and productivity. The timely implementation of critical operations, including the application of quality seeds, fertilizers, and pesticides, as well as efficient harvesting, are essential to enhance vegetable crop yields (Triplett and Dick, 2008).

Potato, a major crop grown in more than 100 countries, ranks 3rd in terms of global production after China and the Russian Federation, with an annual production of about 300 million tonnes (2006-07) (Rout, 2016). In India, potato cultivation has primarily been concentrated in states like Uttar Pradesh, Madhya Pradesh, Bihar, Delhi, Punjab, Haryana, Gujarat, and Himachal Pradesh. The majority of potato cultivation occurs in the subtropical plains (90%), with a smaller percentage in the hills (6%) and plateau regions of peninsular India (4%) (Mehta et al.,2014). The process of harvesting potato crops is laborious, time-consuming, and often leads to significant damage to the potatoes. Manual harvesting causes about 16 to 21% of damage, with 11% attributed to cutting and bruising and the rest remaining undug (Jayan, 2020). To address these challenges and improve the potato cultivation process, the need for appropriate technological interventions, such as a single row automatic potato planter, becomes evident.

This research paper focuses on the development and evaluation of a single row automatic potato planter. The study aims to enhance potato cultivation by optimizing planting operations, reducing labor intensity, and minimizing damage to the potatoes during harvesting. The project also takes into account the suitability of the planter for various tractor power ranges, including mini tractors, which are increasingly being used in India. By achieving these objectives, the research seeks to contribute to the overall improvement of potato cultivation and productivity in the country.

2. MATERIALS AND METHODS

This section outlines the materials used and the methodology followed in conducting the experiments for the proposed study, which aims to design and modify a tractor-drawn potato planter for efficient potato sowing.

2.1 Main Parts of the Unit:

The potato planter consists of essential components, including the seed box designed for smooth seed flow, a sturdy frame providing structural support, a reliable three-point hitch system for tractor connection, an efficient power transmission system, and a precise seed metering mechanism. Additionally, a ridger facilitates furrow and ridge creation, while a well-designed wheel ensures proper ground clearance. These components work synergistically, enabling the planter to sow potato crops accurately and efficiently, enhancing overall productivity in potato farming.

2.2 Design of the Seed Box:

The seed box is designed with a trapezoidal shape to facilitate the free flow of seeds in hopper bottoms. The volume of the seed box is determined by the weight of the seeds and their bulk density. The volume of the seed box (Vb) is calculated using Equation and shown in fig 2.1.

$Vb = 1.1 * Ws * Vs$

Where:
Ws = Weight of seeds in the box, g
Vs = Bulk density of seeds, g/cm3
The dimensions of the seed box are used to calculate its volume as follows:
$Ws = Vs + Vb$

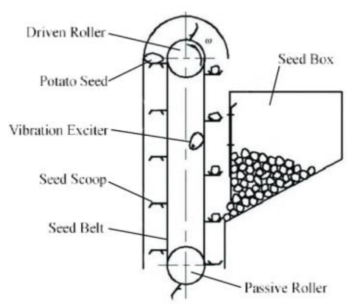

Fig. 2.1Seed box structure

2.3 Power Transmission:

For power transmission, a medium-sized wheel fitted with a sprocket of 12 teeth is selected. The center-to-center distance between the wheel and shaft sprocket is set at 40 cm. A chain length is calculated using the chain pitch and gear ratios for efficient power transmission. The chain drive system is preferred due to its parallel shaft transmission, positive drive, and high transmission efficiency. The formula for calculating the chain length is as follows:

Chain Length (m) = [(C + Z1/P) + (C + Z2/P)] × m

Where,
m=number of chain link
C= center to center distance two sprocket
Z1= number of teeth in driver sprocket
Z2= number of teeth in driven sprocket
P=chain pitch, mm

2.4 Seed Metering Mechanism:

The seed metering mechanism is crucial for the efficient sowing of potato crops. The number of teeth on the sprocket is calculated based on the ground wheel diameter and the required seed-to-seed spacing. The diameter of the sprocket is then determined using the peripheral velocity and revolution per minute.

To calculate the number of teeth on the sprocket (n), use this formula:

$n = (D \times \pi) / (X \times i)$

To determine the diameter of the sprocket (Dr), use this formula:

$Dr = (Vr \times 60) / (\pi \times Nr)$

Where,
n=number of teeth on sprocket
D= ground wheel diameter, cm
X=required seed to seed spacing
i=gear ratio

2.5 Ridger:

The ridger is used for making furrows and ridges for potato crops. It operates in tilled soil with the help of a tractor. The share point penetrates the soil, and the ridger body displaces the soil to create furrows on both sides.

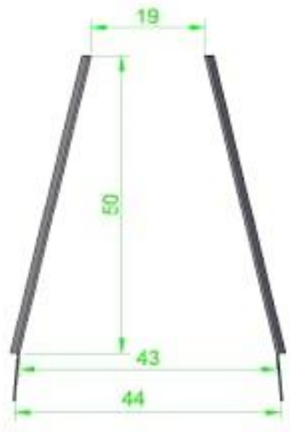

Fig. 2.2 Schematic view of Ridger (Dimensions in cm)

2.6 Design of the Wheel:

The ground wheel diameter is chosen based on the available ground clearance below the seed box to prevent its sinking into the soil. A mild steel sheet with a width of 100 mm and a thickness of 4 mm is selected for the wheel, and the wheel's radius is set at 18 cm.

2.7 Design of the Frame:

The frame of the potato planter is designed to be light yet strong enough to resist shocks due to rough fields or obstacles. It is constructed using closed box sections made of angle iron sheets.

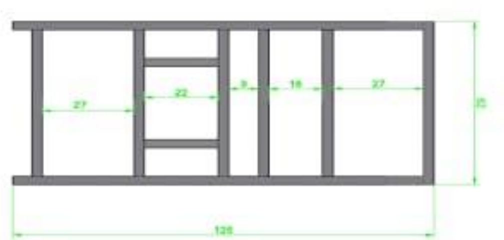

Fig. 2.3 Systematic view of frame (All dimensions in mm)

2.8 Working of the Potato Planter:

The potato planter's seed metering mechanism, driven by the ground wheel, facilitates the free flow and precise spacing of seeds. The furrow opener opens up furrows in which the seeds are planted. As the planter moves forward, the ridger attachment covers the seeds and creates ridges.

The following table presents a comprehensive overview of the various components of the potato planter, including their respective dimensions and materials of construction. These details are crucial for understanding the design and functionality of the planter.

Table 2.1: Components, Dimensions, and Material of Construction for the Potato Planter

S.N.	Name	Dimension	Material
1	Seed Box	51x46x40cm	Mild Steel Sheet 18 gauge
2	Frame	162x62cm	Angle Iron Sheet Steel
3	Chain and Sprocket	1/2" pitch, 1/8" internal width, 3/32" external width, 12 teeth sprocket	Steel
4	Wheel	Φ 36cm	Mild Steel
5	Cups	7x4cm	Mild Steel
6	Three Point Hitch System	30x37.5cm	Mild Steel Bar
7	Furrow Opener	5x20cm	Carbon Steel

In Figure 2.4, presented below, an isometric view and developed prototype of the Automatic Potato Planter designed for Mini Tractors is depicted. The figure provides a three-dimensional representation of the planter, showcasing its structural design and key components, specifically tailored for compatibility with mini tractors. This innovative design aims to enhance efficiency and productivity during potato sowing operations, offering a valuable agricultural tool for small-scale farmers utilizing mini tractors in their cultivation practices.

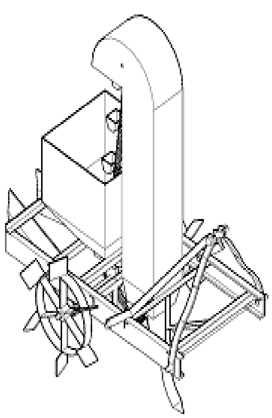

Fig. 2.4 Metering Mechanism of Automatic Potato Planter for Mini Tractor

2.9 Performance Evaluation of the Planters:

The performance evaluation of the potato planter encompasses the analysis of several key variables, classified into two categories: independent and dependent variables. The independent variables include the forward speeds at which the planter operates, with three specific values considered: S1 = 1.5 km/h, S2 = 2 km/h, and S3 = 2.5 km/h. Additionally, the depth of sowing, which significantly impacts the planting process, is evaluated at three levels: D1 = 8 cm, D2 = 10 cm, and D3 = 12 cm.

The effective field capacity is calculated based on the actual area covered by the implement, total time consumed, and its width. The theoretical field capacity, which represents the rate of field coverage, is calculated based on 100% of time at the rated speed and covering 100% of its rated width (Pitla et al., 2014). Field efficiency is then determined as the ratio of effective field capacity to theoretical field capacity, expressed as a percentage. Missing seed percentage is calculated to assess the accuracy of the seed metering mechanism.

Various instruments, such as a stop-watch, measuring tape, and measuring scale, are used for field evaluation. The depth of sowing and speed of operation are measured, and the time required for each operation and turning is recorded using the stop-watch. The total time lost in turning and the total time of operation are calculated for further analysis. This study evaluated the performance of the modified potato planter under different forward speeds and depths of sowing to determine its effectiveness and efficiency in potato cultivation.

3. RESULT AND DISCUSSION

This chapter presents the results obtained from the performance evaluation of the Automatic Potato Planter for Mini Tractors, conducted through field tests. The study aimed to assess the planter's efficiency under varying speeds and depths of sowing, focusing on three key dependent parameters: Effective Field Capacity, Field Efficiency, and Missing Seed Percentage.

Effective Field Capacity:

The effective field capacity was evaluated at different speeds and depths, and the results are illustrated in Figure 3.1. The findings indicate that as the forward speed increases, the effective field capacity also increases. This relationship is attributed to the inverse proportionality between field capacity and the time taken to cover an area. Higher speeds reduce the time required for coverage, resulting in an enhanced effective field capacity. Conversely, as the depth of sowing increases, the effective field capacity decreases, as deeper depths require more time for operation.

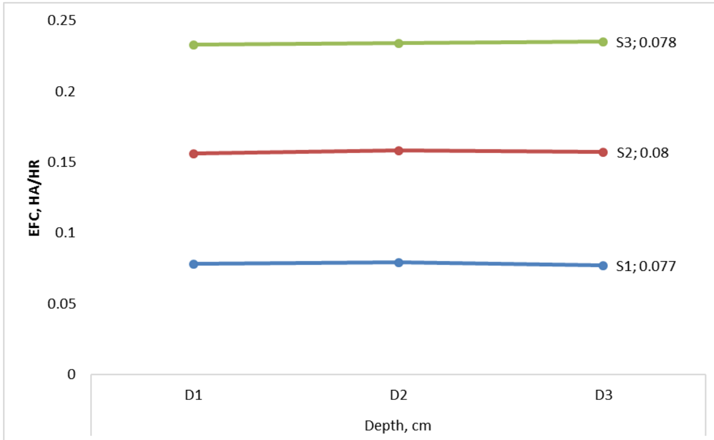

Figure 3.1: Effect of speed and depth on effective field capacity

The maximum effective field capacity of 0.09 ha/hr was recorded at a forward speed of 2 km/hr, while the lowest value of 0.07 ha/hr was observed at 1.25 km/hr and a maximum depth of 15 cm. Analysis of Variance (ANOVA) revealed that both forward speed and depth of operation significantly affected the effective field capacity individually, while their interaction had no significant effect.(Table 3.1).

Table 3.1 ANOVA for the effect of speed and depth on effective field capacity.

ANOVA						
Source of variation	**SS**	***df***	***MS***	***F***	**P-value**	**F-crit**
Speed	0.20258	2	0.10129	355.42R**	1.4F.15	3.55456
Depth	0.00214	2	0.00107	3.75445*	0.04337	3.55656
Interaction	0.0003	4	7.5E.05	0.20472	0.89676	2.92774
Within	0.00513	18	0.00028			
Total	0.21016	26				

Field Efficiency:

Field efficiency, the ratio of effective field capacity to theoretical field capacity, was assessed at different speeds and depths (Figure 3.2). The results indicate that lower speeds correspond to higher field efficiency, with the highest value of 83.6% recorded at 1.25 km/hr. The relationship between field efficiency and speed is attributed to the theoretical field capacity, which is influenced by implement width and speed. Higher speeds reduce the theoretical field capacity, resulting in higher field efficiency.

Moreover, field efficiency increased with an increase in depth, owing to decreased field efficiency values at greater depths. The maximum field efficiency of 83.6% was achieved at 1.25 km/hr and a minimum depth of 5 cm.

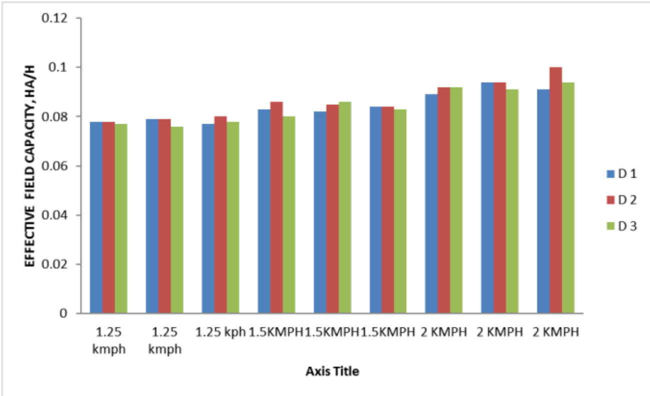

Figure 3.2: Field efficiency (%) at different speeds & depths with replications

ANOVA demonstrated that forward speed significantly influenced field efficiency, while depth of operation and their interaction had no significant impact (Table 3.2).

Table 3.2 ANOVA for the effect of speed and depth on field efficiency

ANOVA						
Source of variation	**SS**	***df***	***MS***	***F***	**P-value**	**F-crit**
Speed	0.20258	2	0.1029	291.174*	2E-14	3.55456
Depth	0.00082	2	0.00041	1.18151	0.32951	3.55656
Interaction	0.00049	4	0.00012	0.35046	0.84028	2.92774
Within	0.00626	18	0.00035			
Total	0.21016	26				

s** Significant value at p-0.05

Missing Seed Percentage:

The percentage of missing seeds was evaluated at different speeds and depths (Figure 3.3). The findings indicate that higher speeds and greater depths resulted in higher missing seed percentages. At 2 km/hr and a depth of 12 cm, the highest missing seed percentage of 8.9% was recorded. The increased missing seed percentage at higher speeds can be attributed to the higher chain velocity, which leaves less time for seeds to fill the cups. At speeds of 1.25 km/hr, the missing seed percentage was comparable for depths of 8 cm and 12 cm. The minimum missing seed percentage of 5.5% was observed at 1.25 km/hr and a depth of 12 cm.

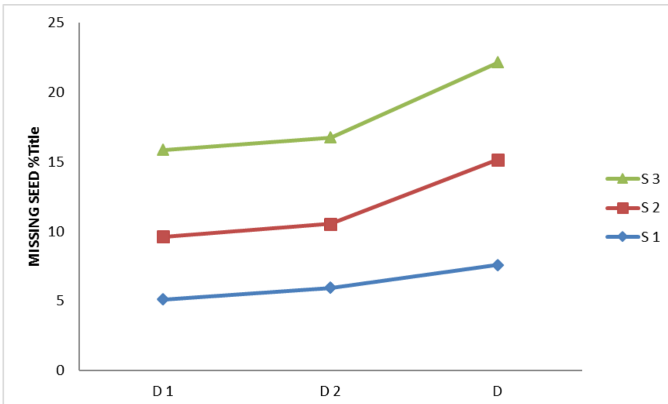

Figure 3.3: Effect of speed and depth on missing seed %

ANOVA revealed that both forward speed and depth of operation significantly affected the missing seed percentage individually, while their interaction had no significant effect (Table 3.3).

Table 3.3 ANOVA for the effect of speed and depth on missing seed percentage

ANOVA						
Source of variation	**SS**	***df***	***MS***	***F***	**P-value**	**F-crit**
Speed	**26.0942**	**2**	**13.4071**	**19.1527***	**3.5E-05**	**3.55456**
Depth	**10.889**	**2**	**5.44448**	**7.99229***	**0.00328**	**3.55656**
Interaction	**3.06865**	**4**	**0.76716**	**1.12617**	**0.37531**	**2.92774**
Within	**12.2619**	**18**	**0.68122**			
Total	**52.3137**	**26**				

Overall, the performance evaluation highlighted the influence of forward speed and depth of operation on the planter's efficiency. Farmers can use these findings to optimize the planter's settings for improved potato planting operations, enhancing agricultural productivity.

4. Conclusion

In conclusion, this research paper presents the development and evaluation of a single row automatic potato planter designed for mini tractors, aiming to enhance potato cultivation and productivity in India. The study evaluated the planter's performance at different speeds and depths, finding that higher speeds increased effective field capacity, while deeper depths decreased it. The most efficient speed was 1.25 km/hr, suitable for mini tractors. Missing seed percentage increased with higher speeds and depths due to chain velocity. Farmers can use this information for better planting decisions. Overall, the planter shows potential to enhance potato cultivation and productivity.

The research demonstrates the viability and effectiveness of the single row automatic potato planter for mini tractors, offering a valuable technological intervention to address the challenges faced in potato cultivation. By reducing labor intensity and enhancing planting efficiency, this planter holds significant potential to improve potato yields and overall agricultural productivity. Overall, the study contributes to the advancement of agricultural technology in India and supports the nation's efforts to achieve food and nutritional security. The findings provide valuable insights for farmers, policymakers, and agricultural stakeholders, encouraging the adoption of mechanized solutions for sustainable vegetable production and economic growth. In conclusion, the successful development and evaluation of the single row automatic potato planter showcase its potential as a practical and efficient tool for farmers, enabling them to meet the growing demands for nutritious vegetables and contribute to India's agricultural prosperity. Future research may focus on optimizing and scaling up the planter for larger fields and exploring additional technological advancements to further revolutionize potato cultivation in the country.

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