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Development and evaluation of self-propelled Planter for seeding in terrace farming conditions

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ABSTRACT

A light weight two row self-propelled planter for terrace farming was developed, and its performance was evaluated for planting buckwheat seeds. Laboratory testing was conducted to evaluate the performance and optimize the operating parameters. The independent variables considered were peripheral speed of seed plate (0.28, 0.42, 0.50, 0.55 m s^{-1}), cell size (5.2,6.2, 6.8, 7.0 mm) and gate opening height (10, 30, 50, and 70 mm). The response considered were missing index, multiple index, feed index and degree of variation. The experiments were planned using afull factorial design. Analysis of variance indicated that effects of peripheral speed of seed plate and cell size on the responses were significant, while the gate opening height did not affect the performance significantly. The independent parameters were optimized by numerical optimization technique by using the desirability function of Design Expert software. The objective of the optimization was set to minimize missing index, multiple index, degree of variation and maximize feed index. The solution with highest desirability value was taken as the optimum. The optimum performance was obtained at 6.2 mm cell size, 0.28 m s^{-1} peripheral speed of seed plate and 30 mm gate opening height with missing index, multiple index, degree of variation and maximum feed index of 10.0 %, 15.0 %, 75.30 %, and 16.39% respectively. The planter was then tested in field for sowing buckwheat seeds at the optimized operating conditions. The theoretical field capacity, actual field capacity and field efficiency of the planter was found to be 0.06 $ha.h^{-1}$, 0.04 $ha.h^{-1}$ and 68% respectively. Seed rate for planting of buckwheat was found 16.7 kg ha^{-1}, which was much lower than the broadcasting seed rate of 40 $kg.ha^{-1}$.

1. Introduction

Mechanization plays important role in improving agricultural production by maintaining timeliness of various operations, increasing the intensity of cropping, ensuring precise use of costly inputs and reduction in drudgery. Seeding is the most important or key farm activity among the different farm activities. Sowing of seeds at desired depth with proper seed rate and spacing significantly impacts the yield of the crop (Veeranagouda and Shridhar, 2010). Thus, there is a significant role of seed planters (power tiller or tractor drawn) for majority of crops for boosting the agricultural production and productivity.

A planter is a farm machine used for sowing seed at recommended depth and spacing, covering the seed and compacting the soil around it to ensure proper germination. The metering mechanism of the planter pick up the seeds from the hopper and drop them into the conveying pipe. A cut-off mechanism eliminates the excess seeds carried out in the seed plate cells and permitsonly a correct number of seeds for delivery. Seed fall into the delivery pipe and reach at the furrow. The precision of the planter depends upon various factors such as the forward speed, peripheral speed of seed plate, size and shape of cells, shape of hopper, shape and uniformity of seed size. Furrow openers and metering systems are the important parts of planter. In general, furrow opener cuts or loosens a narrow slot of specified depth to obtain desired seed placement and soil coverage. Based on the soil conditions and applications, different types of furrow openers are used such as shoe, hoe, shovel, runner, single disc, double disc and inverted-T type.

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Planting of crops helps in judicious use of costly inputs along with increased input use efficiency and timeliness. The literature survey indicates that most of the planters developed are mainly tractor operated or manual. Under terrace farming, tractor operated planters cannot be adopted due to their heavy weight and large size. For terrace farming, the design of farm machinery must be compact, small in size, light in weight, and center of gravity as low as possible for higher stability.

In Sikkim, the sowing of buckwheat is done using the conventional method (broadcasting). The limitations of this method are high seed rate, poor germination and low plant population. The broadcasting method is a bottle neck in mechanization of subsequent farm operations. To achieve the potential yield, seeds have to be placed in the soil at the recommended depth and spacing in the recommended sowing time.The optimum planting depth of the buckwheat seeds is 30 to 50 mm, row spacing 300 – 450 mm and plant to plant spacing of 100 – 150 mm (Anon., 2006). This can be fulfilled by performing mechanical placements of seed using a suitable planter. Therefore, a self-propelled walk behind type small planter was developed and evaluated in the present study.

2. Materials and Methods

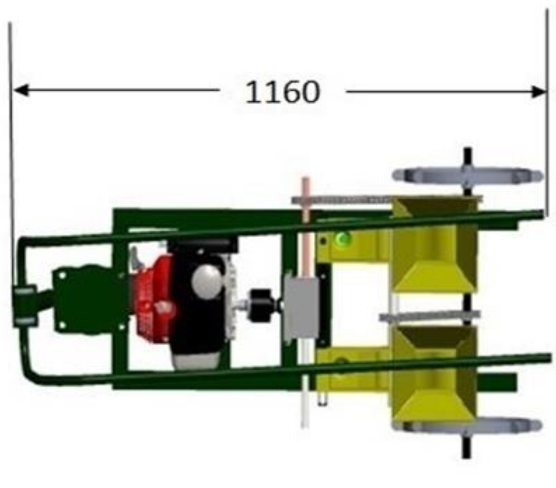
The design of the planter was conceptualized as a two-rowself-propelled un it powered by a small petrol engine. The machine was provided vertical plates with cell for seed metering. The CAD model of the design is shown in Fig.1. The designed planter prototype was fabricated in the college workshop. The performance of the planter was tested in the laboratory condition for sowing buckwheat seeds and the operating parameters were optimized. Then, the planterwas evaluated in the field for sowing buckwheat by operating the planter in optimum conditions.

2.1 Description of the developed planter

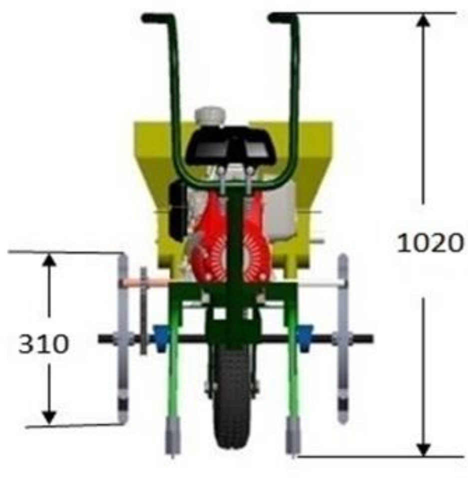
The developed planter consisted of engine, power transmission system, seed hoppers, seed metering system, furrow openers and frame. The developed planter is shown in Fig.1(c). The various components of the developed planter is discussed below.

2.1.1 Power transmission system

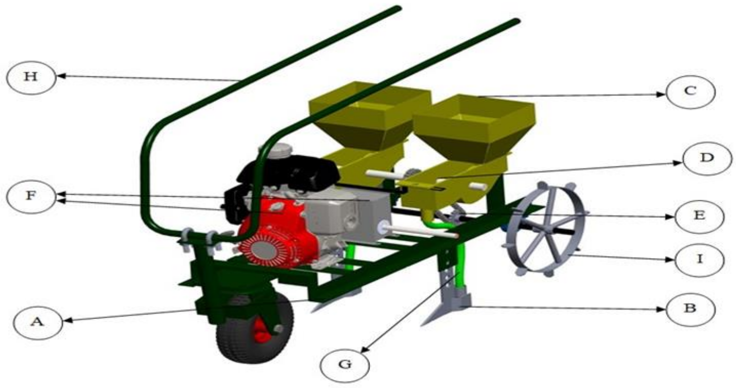
A 2.1 kW, 3600 rpm rated speed gasoline engine was used to supply the power required for the self-propelled planter. The power from the engine was transmitted to gear box of 60:1 reduction ratio through a centrifugal clutch. The power from the gear box was then transmitted to ground wheel by chain and sprocket drive for obtaining desired speed of the ground wheel. Power to the seed metering unit was given from the ground wheel shaft in 1:1 speed ratio by using chain and sprocket drive.



(a). Top view



(b). Front view



(c) Isometric view

Fig. 1. CAD model of the designed self-propelled planter

(A: Frame of planter, B: Furrow opener, C: Seed box, D: Seed metering mechanism, E: Chain Sprocket, F: Engine and Gearbox, G: Seed conveying pipe, H: Handle, I: Rear wheel)

2.1.2 Seed metering mechanism

The metering mechanism of the planter consisted of vertical seed plates of 100.0 mm diameter and 5.0 mm thickness made of plastic.Ten cells at 31.4 mm circular spacing was cut at the periphery of the plate to use it in the vertical plate metering system. The size of the cell was selected based on the size of the buckwheat seed. The seed plates were mounted in the secondary seed box and a gate was provided to regulate the seed flow from the main seed box in to the secondary seed box. The height of seed in the secondary seed box could be maintained at desired level by adjusting the gate opening height.

2.1.3 Dog clutch system

The metering system need to be stopped during turning the machine at head lands in order to prevent seed wastage. Usually in small planters or drills a separate ground when is provided, which is lifted during turn to stop the metering system. In the developed planter, in order to eliminate the requirement of a separate ground wheel and reduce weight of the machine, a dog clutch system was used to connect and disconnect power transmission from theground wheel 2.driving shaft to the metering shaft. The god clutch consisted one driver and another driven plates. The male female groves made on the plates fits into each other when the clutch is engaged. The driven part is mounted on the shaft over a key on the ground wheel shaft and can slide over the shaft, while the driving part is mounted rigidly on the ground wheel shaft. The driven part is spring loaded and the spring pushes the driven part towards the driving part. While in operation the clutch is engaged by the spring force and a sprocket attached to the driven part transmits power to the metering system. During turns the dog clutch can be disengaged by shifting the driven part farther from the driving part with the help of a shifting lever, thereby disengaging power to the metering system. The dog clutch system is shown in Fig.

Figure 2. Dog clutch system used for power transmission from ground wheel to metering system

2.1.4 Steering system

The steering system consists of a single caster wheel at the front of the machine and handle. The handle can be turned to steer the machine during turns.

2.2 Performance evaluation in laboratory

The seeding performance of the developed planter was studied in the laboratory by the sand bed method as per BIS test code IS 6316: 1993.The planter was tested at four levels of peripheral speed of seed plate (0.28, 0.42, 0.50, 0.55 m s^{-1}) four levels of cell size (5.2,6.2, 6.8, 7.0 mm) and four levels gate opening height (10, 30, 50, and 70 mm). The performance of the planter was assessed in terms of missing index, multiple index, feed index and degree of seed spacing variation. The experiments were planned in a full factorial multilevel categorical design with three replications. The analysis of variance was done to study the effect of various independent parameters on the responses. The operating parameters were optimized in relation to the responses through numerical optimization technique using the desirability function of the Design Expert software (Ver. 11.1). The objective of the optimization was to minimize missing index, multiple index, degree of variation and maximize feed index. The solution with highest desirability value among the predicted solutions was taken as the optimum.

2.2.1 Missing Index

Missing index (I_m) is the percentage of spacing greater than 1.5 times the theoretical spacing and it was calculated by using the following equation (Grewal *et al.*, 2015).

$$I_m = \frac{n_1}{N} \times 100 \qquad \ldots(1)$$

Where, I_m = Missing index (%), n_1 = Number of spacing ≥1.5 times of the theoretical spacing and *N* = Total numbers of measured spacing.

2.2.2 Multiple Index

Multiple index includes two or more seeds picked and dropped by the seed metering unit by a single groove in the metering plate. Multiple index is an indicator of more than one seed dropped within the desired spacing and it was calculated by using the following standard relationship (Grewal et al., 2015).

$$I_{mu} = \frac{n_2}{N} \times 100 \qquad \ldots(2)$$

Where, I_{mu} = Multiple index (%)

n_2 = Number of spacing $\leq$ 0.5 times of theoretical spacing

N = Total numbers of measured spacing.

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2.2.3 Degree of variation

Degree of variation is a measure of the variability in the spacing of the seeds after removing the variability due to skips and multiples. It is the coefficient of variance of the spacing that are classified as single and it was calculated by the following equation (Grewal et al., 2015).

$$V_d = \frac{S_d}{S} \qquad \ldots(3)$$

Where, S_d = Standard deviation of the spacing more than half but less than 1.5times the theoretical spacing

S = Theoretical spacing between two seeds

2.2.4 Feed index

Feed index is the measure of how often the seed spacing's were close to the theoretical spacing. It is the number of observations, which is 0.5 to 1.5 times theoretical spacing. Higher the feed index better is the performance of the metering mechanism (Sahu and Verma 2016).

$$F_i = \frac{n_3}{N} \times 100 \qquad \ldots(03)$$

Where, F_i = Feed index (%)

n_3 = Number of observations, which are 0.5 to 1.5 times of the theoretical spacing;

N = Total number of observations.

2.3 Field performance evaluation

The performanceof the developed planter was evaluated in the farmer's field for sowing buckwheat seed. The performance parametrs such as field capacity, field efficiency, seed rate and depth of sowing were determined during the field study following the BIS standard test code (IS 6316:1993).

2.4 Cost economics

The cost economics of operation of the developed planter was calculated by working out the total cost of the machine, fixed costs and the running cost of the equipment. The breakeven point and payback period for the unit was also calculated by considering the fixed costs and the variable costs (IS: 9164- 1979).

3. Results and Discussion

3.1 Results of laboratory study

3.1.1 Effect of independent operating parameters on missing index

The missing index was found to vary between 01% to 19%between different treatments combinations. ANOVA indicated that the effect of peripheral speed of seed plate and cell size significantly affected missing index, while the effect of gate opening height was found to be statistically non-significant. The effect of peripheral speed of seed plate and cell size on missing index is depicted in the Fig.3.

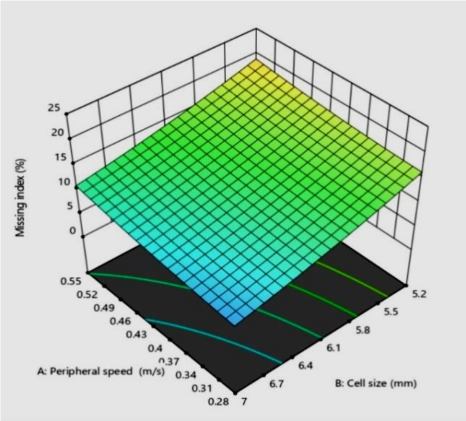

Figure 3. Effect of peripheral speed of seed plate and cell size on missing index.

It was observed that as the peripheral speed of seed plate increased 0.28 to 0.55 m s^{-1}, the missing index also increased. It may be due the fact that when the speed is higher, the available time to fill the cell was very less and cell moves forward without carrying the seed in it. The results obtained are in agreement with the findings of Reddy et al.,(2012) and Kumar et al.,(2015). The variation of missing index with cell size is shown in Fig.3. It was observed that missing index (I_m) decreased with increase in cell size from 5.2 to 6.8 mm. It may be due to the fact that when cell size is large, there is always a chance that at least one or two seeds will be filled up in the cell. The results obtained are in agreement with the findings of Singh et al., (2012).

3.1.2 Effect of independent operating parameters on multiple index

The multiple index was found to vary between 08% to 46%between different treatment combinations. ANOVA indicated that the effect of peripheral speed of seed plate and cell size significantly affected multiple index, while the effect of gate opening height was found to be statistically non-significant. The effect of peripheral speed of seed plate and cell size on missing index is depicted in the Fig.4.

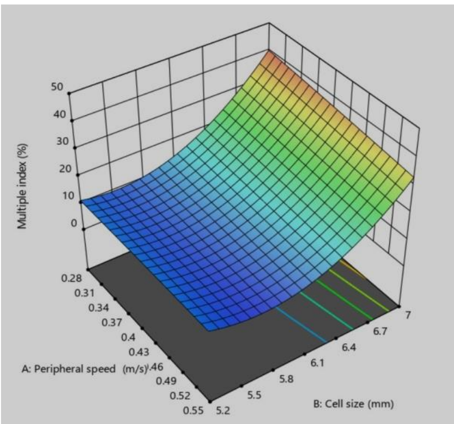

Figure 4. Effect of peripheral speed of seed plate and cell size on multiple index

The variation of multiple index with peripheral speed of seed plate is shown in Fig.4, it was observed that as the peripheral speed of metering plate increases, the multiple index decreases. The high cell fills at a slower speed is due to the high frequency of multiple seed drops because of the more pickup time of cells. This results obtainedare similar with the findings reported by Reddy *et al.*, (2012) and Bhimani*et al.*, (2019). The variation of missing index with cell size of seed metering plate is shown in Fig.4, it is can be observed that multiple index (I_{mu}) increases with increase in cell size. It may be due to the fact that when cell size is large, there is always a chance that more than one seeds will be filled up in the cell in short available time. Similar results have been reported by Singh *et al.*, (2012) and Reddy *et al.*, (2012).

3.1.3 Effect of independent operating parameters on feed index

The feed index was found to vary between 52% to 79%between different treatments combinations. ANOVA indicated that the effect of cell size significantly affected feed index,while the effect of peripheral speed of seed plate and gate opening height was found to be statistically non-significant. The effect of cell sizeon feed index is depicted in the Fig.5.

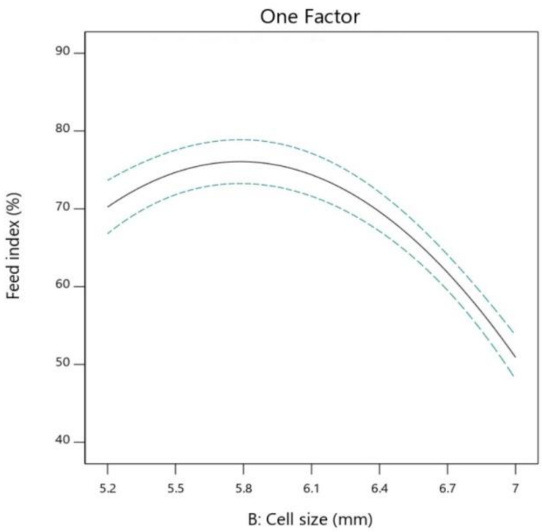

Figure 5. Effect of cell size on feed index

The variation of feed index with cell size of seed metering plate shows that feed index (F_i) decreases with increase in cell size. It may be due to the fact that when cell size is large the occurrence of multiples increased. This observed trend is similar with the findings reported by Singh *et al.*, (2012) and Kumar *et al.*, (2015).

3.1.4 Effect of independent operating parameters on degree of variation

The degree of variation was found to vary between 16.01 to 23.12 between different treatments combinations. ANOVA indicated that the effect of peripheral speed of seed plate and cell size and gate opening height significantly affected degree of variation. The effect of peripheral speed of seed plate, cell size and gate opening height on degree of variation is depicted in the Fig.6.

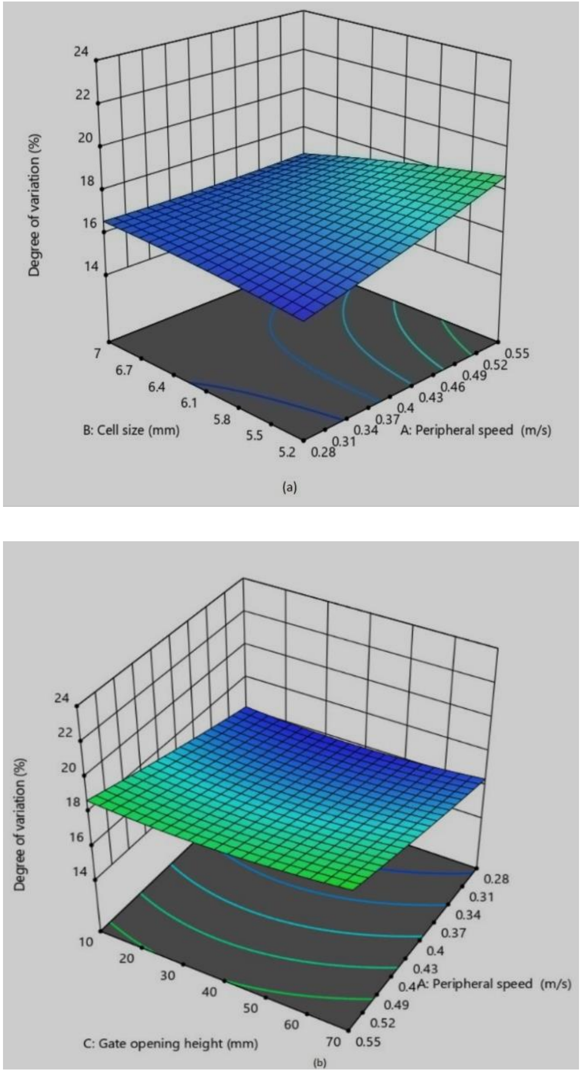

Fig.6. Effect of peripheral speed of seed plate, cell size and gate opening heighton degree of variation

The degree of variation with peripheral speed of seed plate is shown in Fig.6 (a) and (b), it is observed that as the peripheral speed of seed plate increases, the degree of variation increase. The degree of variation with cell size of seed metering plate is shown in Fig. 6 (a), it was observed that degree of variation (V_d) decreases with increase in cell size. The effect of the gate opening height on degree of variation (V_d) is shown in Fig.6 (b). From the graph, it was observed that, degree of variation (V_d) is slightly affected by the gate opening height from 10 to 70 mm. The results are in agreement to the findings reported by Gautam *et al.*, (2019) and Patel (2020).

3.1.5 Optimization of the operating parameters

The numerical optimization was done using desirability function of Design Expert Software. A total of 33 predicted solutions were obtained. The solution with maximum desirability of 0.852 was taken as optimum. The optimum solution was obtained at peripheral speed of of 0.28 m s^{-1}seed plate, cell size of 6.2 mm, and gate opening height, of 30.0 mm with the missing index, multiple index, feed index and degree of variation of 10.0 %, 15.0 %, 75.30 %, and 16.390 %, respectively. The result was experimentally validated in the laboratory as the experimental results were found to be in close agreement to the predicted solution.

3.2 Field performance of the developed planter

The planter was operated in the field for sowing buckwheat seed at the optimized operating conditions and the results are given in table.1.

Table.1. Field Performance data of the developed planter

Performance parameters	Value
Depth of placement, cm	3.0
Forward speed, km.h^{-1}	1.0
Theoretical field capacity, ha h^{-1}	0.06
Field capacity, ha.h^{-1}	0.041
Field efficiency, %	68
Seed rate, kg/ha	16.7
Soil moisture content before sowing:	19.57±2.72

3.3 Cost economics

The total cost of the developed planter was estimated as Rs. 38000. The fixed cost and variable cost of the developed planter was 40.00 Rs.h^{-1} and 280.00 Rs.h^{-1}, respectively. The total cost of operation of the developed planter was found to be 320 Rs.h^{-1}. The breakeven point for the developed planter was found to be 50 h.$yr^{-1}$of annual usages. Therefore, the payback period of the developed planter was estimated at 0.52 year.

4. Conclusions

A self-propelled small planter was designed and developed for sowing buckwheat seed. The optimum operating parameters for peripheral speed of seed plate, cell size and gate opening height were found to be 0.28 m s^{-1} 6.2 mm and 30.0 mm respectively for planting buckwheat seeds. At the optimum operating conditions, the missing index, multiple index, feed index and degree of variation were found to be 10.0 %, 15.0%, 75.30%, and 16.39%, respectively. The desirability was maximum i.e., 0.852, as a result, for field testing of the designed for self-propelled buckwheat planter. Seed rate of the developed planter was only 16.7 kg ha^{-1}as compared to the seed rate of 35 - 40 kg ha^{-1}used in the traditional broadcasting practice. The total cost of operation of the developed planter was found 320 Rs.h^{-1}. The breakeven point and payback period for the developed planter was estimated as 50 h.yr^{-1} and 0.52 yrrespectively.The developed planter may also be used for sowing other crops by minor changes in the metering system. The developed planter is light weight, small and suitable for cultivation on terrace lands.

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