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# Microcontroller based Automatic Spot Granular Fertilizer Dispensing Machine for Orchards

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A healthy orchard necessitates well-balanced nutrition. In order to achieve a high yield, fertilizer application in the proper amount and position is important. Existing fertilizer application methods (band placement, pellet application, and ring basin method) have limitations such as excessive fertilizer application, soil acidity, nutrient imbalance, soil structure damage, bulk density rise, and more. A spot fertilizer applicator that can dispense the proper amount of fertilizer at right site can reduce fertilizer waste, lowering pollution and input costs. As a result, a novel grooved belt type metering system was designed with an autonomous plant detection-based spot fertilizer application. The fertilizer placement and consistency of amount dispensed per plant of the applicator were assessed in the lab. The independent parameters were metering belt groove volume (50, 100 and 150 $cm^3$), metering belt speed (8, 9 and 10 $m.min^{-1}$), plant spacing (45, 60, 75 and 90 cm) and forward speed (2, 2.5 and 3 $km.h^{-1}$). Forward speed had a considerable impact on the band length, whereas groove volume and belt speed had a substantial impact on the lateral placement parameters. Because plant spacing had no significant effect and the means of real and measured fertilizer application amounts were equal, the machine was found suitable for applying fertilizer with any plant spacing. Using a full factorial experimental design, the optimal values for independent parameters such as groove volume, plant spacing, belt speed, and forward speed were assessed 50 $cm^3$, 78.4 cm, 8.74 $m.min^{-1}$, and 2.72 $km.h^{-1}$, respectively with a high desirability of 0.971. In comparison to mechanical sensing type available spot fertilizer applicators, the developed spot fertilizer applicator required half the sensing and actuation time and had three times less fluctuation in fertilizer dosing.

**Keywords:** Band length, Band spacing, Grooved belt metering, Precise fertilizer placement, Ultrasonic plant detection

## Introduction

Farmers use chemicals fertilizers that increase crop yield, to maintain their crop yield. Nitrogen, potassium, and phosphorus are among the fertilizers, and they are all essential nutrients for plants. These fertilizers increase soil fertility while improving its water retention capacity. Nutrients must reach the root zone in order to absorb essential elements by the plants. Root interception, mass flow, and diffusion are the three primary mechanisms that govern the movement of ions from soil to roots. Excessive application of these nutrients in the form of fertilizer can have serious consequences for the environment and the health of humans and other creatures. Fertilizers leak into groundwater and level of hazardous chemicals in groundwater rises as more fertilizer is applied to the soil. Hence, fertilizer application at the right time, in the right place, and in the right amount is crucial, especially in orchards with commercial value.

A healthy orchard needs good soil that should be in rich nutrients. Balanced nutrients also have an impact on the quality of orchard crops, namely the color, shape, size, flavor, shelf life and processing qualities. Many orchard crops are strong nutrient consumers (can absorb 500 to 1000 kg of N + $P_2O_5$ + $K_2O$ $ha^{-1}.yr^{-1}$) and maximum yields can only be achieved by applying these nutrients with optimal amounts and in appropriate proportions at the right place.[1] The most common methods i.e., band placement, pellet application and ring basin are usually used for application of granular fertilizers in orchards. As orchards are wide spaced crops, continuous application leads to wastage of fertilizer.[2–7] The potential risk involved in excessive use of fertilizers (i.e., soil acidification, growing pests, release of greenhouse gases, nutrient imbalance, soil structure destruction, bulk density increase) in agriculture production system has forced the researchers to

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develop various methodologies for precise and control application of fertilizers in the field.[3] Spot placement of fertilizer in bands near the plant, rather than uniform distribution over the entire area, results in more effective utilization of the nutrients by the plants.[3] Hence, placement of fertilizers at recommended location with respect to plant is of utmost importance to enhance use efficiency and saving in input cost. At present, different mechanical means available for fertilizer application in general, but fully orchard crop compatible machines are very less. Therefore, manual ring basin and pallet fertilizer application is being followed at farmers' field. All these practices are having certain demerits such as labour intensive, time consuming, low fertilizer use efficiency, non-uniform application of fertilizer per plant.

Moreover, spot application has potential in saving fertilizer and also, metered quantity of fertilizer ensures uniform application for each plant, reducing fertilizer input cost and degradation of environment due to excess use of fertilizers. The spot dispensing of fertilizers in orchards can be achieved by various mechanical and electronic control units. Mechanical sensing-based spot fertilizer applicators with ground wheel powered metering system were developed in the institute had more sensing and fertilizer dispensing time and larger variation in fertilizer application rate per plant.[8,9] Since, the reliability, accuracy and response of electronic based controlled unit is better compared to mechanical unit.[10,11] Therefore, the development of a microcontroller based automatic plant detection and spot granular fertilizer dispensing machine for orchard was carried out.

### Theoretical Considerations

***Band Length:*** It is the length of band of the fertilizer applied near a plant (Fig. 1b).

***Fertilizer Placement Inside:*** It is the distance of inner point of the fertilizer band applied from the center line of the plant row (Fig. 1b).

***Fertilizer placement Outside:*** It is the distance of outer point of the fertilizer band applied from the center line of the plant row (Fig. 1b).

***Band Width:*** It is the width of the fertilizer band applied near the plant. Generally, it is the difference of fertilizer placement inside and outside (Fig. 1b).

***Application Amount:*** It is defined as the amount of fertilizer applied per plant (Fig. 1a).

## Materials and Methods

The methodology that was utilized for the development of the spot granular fertilizer dispensing system is depicted in Fig. 2. The sonar sensing mechanism was utilized to detect the plant canopy and trigger the stepper motor so that the fertilizer could be dispensed in the root zone. After that, an experiment using a soil bin was carried out in order to fine-tune the control parameters. The refined parameters served as the foundation for the development of the final prototype. The developed machine was evaluated in real-field condition. The detailed methodology has been broken down into its component parts below.

### Design of Fertilizer Metering Mechanism

Fertilizer application in orchards require larger metering capacity compared to field crops.[1] Conventional fertilizer metering mechanisms had either lower metering capacity or accuracy.[8,9] Therefore, a new metering mechanism was needed that can dispense fertilizer at a higher application rate with accuracy. To overcome this problem a new metering mechanism based on the volume of fertilizer to be delivered was developed using multiple grooved green PVC belt. The design of fertilizer metering mechanism was carried out with following design considerations:

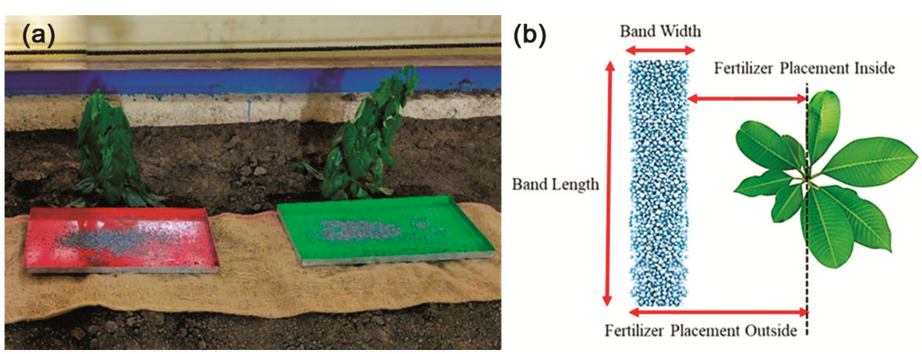


Fig. 1 — Terminologies used for fertilizer placement

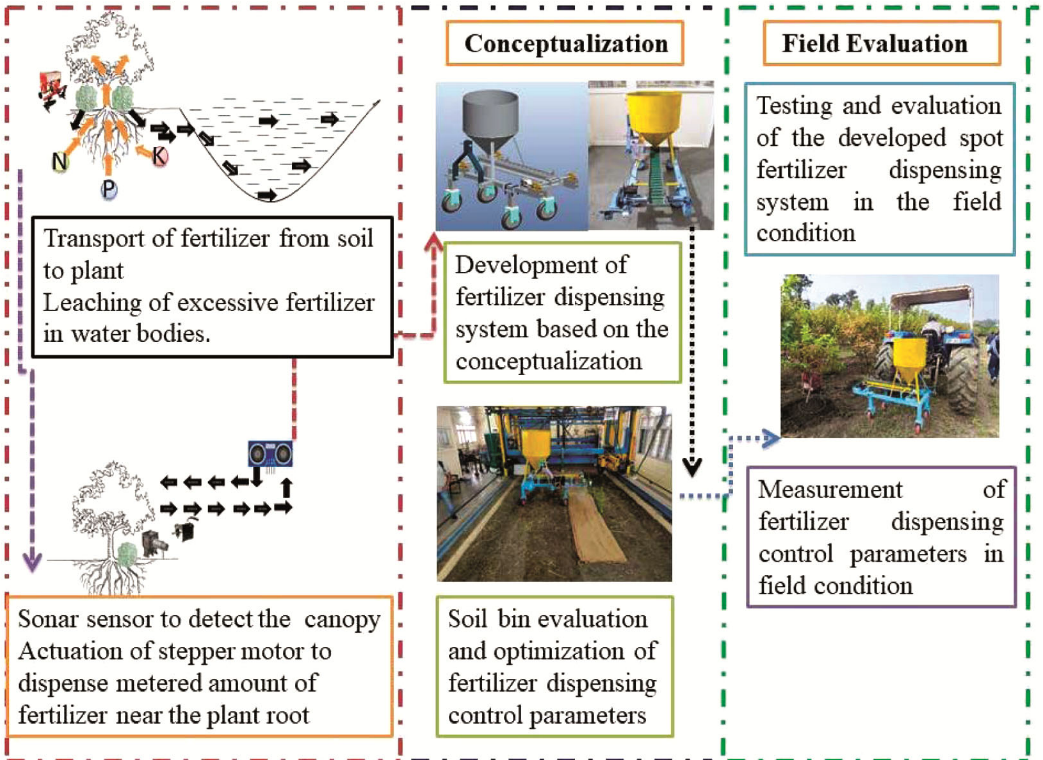


Fig. 2 — Methodology for development of spot fertilizer applicator

1. Fertilizer dose per plant ranges between 0.05 to 0.25 kg per split.[1]
2. Forward speed of the tractor operated fertilizer applicator machine ranges between 2 to 3 $km.h^{-1}$ in orchards.[8,9,12,13]
3. The target band length of fertilizer application is 0.25 m near the plant.[8,9]
4. Linear speed of the fertilizer metering belt ranges between 8 to 10 $m.min^{-1}$ based on 10 N.m torque availability at stepper motor end.
5. Minimum size of belt groove possible to be fabricated 100×25×20 mm.
6. Maximum trackwidth of the general-purpose tractor in India is 2000 mm.

In the view of theoretical considerations, the design values for metering mechanism were determined. The total time available for dispensing the required amount of fertilizer in a band of 0.25 m was calculated using Eq. 1. The maximum forward speed of the machine was taken 3 $km.h^{-1}$.

$$t = \frac{3.6 \times B_l}{F_s} \quad \ldots (1)$$

where, t = total time available for delivery of fertilizer (s), $B_l$ = band length of fertilizer placement (m), $F_s$ = maximum forward speed during machine operation ($km.h^{-1}$). The time available was obtained 0.3 s by substituting the values of $B_l$ and $F_s$ in Eq. 1.

The maximum linear speed of the metering belt required was calculated using minimum pitch of the belt grooves (30 mm), maximum application dose per plant (0.25 kg) and minimum time available (0.3 s). This maximum linear speed of metering belt was calculated using Eq. 2.

$$L_s = \frac{Q \times L \times 60}{q \times t} \quad \ldots (2)$$

where, $L_s$ = linear speed of belt ($m.min^{-1}$), Q = fertilizer dose per plant (kg), q = amount of fertilizer per groove (kg), L = groove spacing (m). Substituting the values of Q, L, q and t as 0.25 kg, 0.03 m, 0.15 kg and 0.3 s in Eq. 2, maximum linear speed of the metering belt was calculated as 10 $m.min^{-1}$. The calculated value of linear belt speed was within the range (3.5 to 12.5 $m.min^{-1}$) of the available DC motor.

The fertilizer dropping point was kept 1000 mm offset from the centerline of the tractor to ensure the placement of fertilizer near the root zone of the plant. The fertilizer box was kept near the centerline of the tractor and the length of metering belt was taken as distance between the bottom of fertilizer box to the dropping point of fertilizer near the root zone of the plant. The total length of endless metering belt was 2090 mm. The metering belt was mounted on two nylon rollers having inner and outer diameters of 25 and 50 mm, respectively. The nylon rollers were keyed over mild steel shafts with 25 mm diameter and 530 mm length. Both ends of shafts were supported with universal pillow bearings (UCP204). The thickness of green PVC belt was 3 mm.

### Design of Fertilizer Containment Tray

There were no sidewalls on the grooved belt to restrict the fertilizer while metering and dispensing. Therefore, a containment tray was fabricated with a cross-section of C-type. The height and width of sidewalls were 50 and 110 mm.

Black expanded polyethylene (EPE) foam sheets (density 30 $kg.m^{-3}$, elongation 90% and working temperature −50 to 70°C) were pasted inside containment tray at the side walls to protect the side flow of fertilizer. EPE foam sheet has lower coefficient of friction between fertilizer and foam sheet compared to the friction between mild steel sheet and fertilizer granules. The thickness of the EPE foam was 5 mm on each side. The complete assembly of developed metering mechanism is shown in Fig. 3.

### Design of Gravity Flow Fertilizer Box

The metering mechanism was designed for a maximum application rate of 0.25 kg of fertilizer per plant at a forward speed of 3 $km.h^{-1}$ and the metering belt speed of 10 $m.min^{-1}$. The following design considerations were used while designing gravity flow fertilizer box:

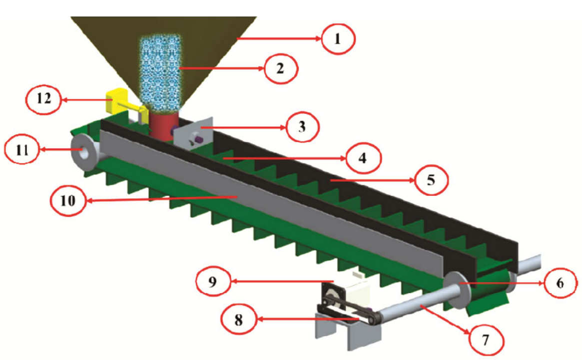


Fig. 3 — Fertilizer metering and dispensing mechanism: [1. Fertilizer hopper 2. Fertilizer 3. Scrapper leveler 4. Green PVC belt 5. Black EPE foam sheet 6. Nylon roller (Driver) 7. Driving shaft (MS) 8. Timing belt 9. Stepper motor 10. Containment tray 11. Nylon roller (Driven) 12. Hopper closing mechanism]

1. The recommended capacity of fertilizer box was 0.1 – 0.15 $m^3$ for tractor mounted machine.[14]
2. The maximum angle of repose was calculated to be 30° for Di-ammonium Phosphate (DAP) fertilizer.
3. A cylindrical with conical section at bottom was selected for fertilizer box to ensure easy flow of fertilizer.
4. Density of DAP was determined as 1020 $kg.m^3$.
5. The average particle diameter determined was 3.2 mm.

The flow rate of fertilizer necessary to support the seamless metering and dispensing of fertilizer was a critical parameter in designing the fertilizer box. It was calculated using Eq. 3.

$$W = \frac{Q}{t} \quad \ldots (3)$$

where, W = mass flow rate required ($kg.s^{-1}$), Q = fertilizer dose per plant (kg), t = total time available for delivery of fertilizer (s). The required flow rate of fertilizer was calculated 0.833 $kg.s^{-1}$ by substituting the fertilizer application rate per plant (0.25 kg) and minimum time available (0.3 s) using Eq. 3.

This flow rate was used to calculate the opening size for required fertilizer application rate. The bottom opening of fertilizer box was calculated using the Beverloo equation[15] for the flow of granular material through circular orifice (Eq. 4)

$$W = 0.58\rho_B\sqrt{g}\left(D_0 - 1.4d\right)^{2.5} \quad \ldots (4)$$

where, W = mass flow rate ($kg.s^{-1}$), $\rho_B$ = bulk density of the fertilizer ($kg.m^{-3}$), g = acceleration due to gravity (9.81 $m.s^{-2}$), $D_0$ = Diameter of the bottom opening (m), d = average particle diameter (m). Substituting the values of W, $\rho_B$, g and d as 0.833 $kg.s^{-1}$, 1020 $kg.m^{-3}$, 9.81 $m.s^{-2}$ and 0.0032 m, respectively in Eq. 4, the required circular opening diameter was calculated to be 0.05 m. The required volume of the fertilizer box was assumed 0.1 $m^3$ for a tractor operated machinery.[14] This total volume of the box having cylindrical as well as conical section was calculated using Eq. 5.

"Total volume of box = volume of cylindrical part + volume of conical section"

$$V = \frac{\pi}{4}D^2H_1 + \frac{\pi}{12}\left(D^2 + DD_0 + D_0^2\right)H_2 \quad \ldots (5)$$

where, V = total volume of the box ($m^3$), D = diameter of the cylindrical hopper (m), d = orifice opening at the bottom (m), $H_1$ = height of cylindrical portion (m), $H_2$ = height of the conical section (m). The total volume (V) and diameter of the conical bottom ($D_0$) were substituted as 0.1 $m^3$ and 0.05 m in Eq. 5. Height of the conical section was calculated using the half cone angle similar to the angle of repose of the DAP fertilizer (Eq. 6).

$$H_2=\frac{D-D_0}{2\tan\theta} \quad \ldots (6)$$

The diameter of the cylindrical section was assumed 0.5 m whereas, the half cone angle was taken as 30° in Eq. 6 to calculate the height of conical section. The height of the conical section was found 0.39 m (≈ 0.4 m). The values of V (0.1 $m^3$), D (0.5 m), $D_0$ (0.05 m) and $H_2$ (0.4 m) were substituted in Eq. 5 and calculated the value of $H_1$ as 0.49 m (≈0.5 m). The fertilizer box was fabricated using mild steel sheet of 1.6 mm thickness. The fertilizer box was supported by four legs of 50 × 5 mm MS flat and mounted over the main frame.

### Furrow Opener and Closer

Furrow opener was used to make a deep passage for placing the fertilizer near the plant. Considering the untilled hard soil near the orchard plants along with the stubbles, the disc type furrow opener was selected for fertilizer application.[16] The disc had 350 mm diameter with a concavity of 35 mm. The shaft diameter was 20 mm. The thickness of the disk was 3 mm. The disc furrow opener was placed 0.25 m ahead of the fertilizer dropping point at an angle of 30° from the direction of travel. A flat sheet of 12 mm was welded on the frame which had adjustment for the offset length.

### Design of Machine Frame

A machine frame was fabricated for mounting of fertilizer box, fertilizer metering mechanism, furrow opener, furrow closer, plant sensing and fertilizer dispensing unit. The frame was made up of mild steel square sections of 50 × 50 × 5 mm (Fig. 4a). The size of the frame was 1980 × 710 × 500 mm. The frame was supported over four legs of mild steel square section of 50 × 50 × 5 mm. Four nylon wheels (100 mm diameter) were attached in the bottom of legs.

The fertilizer box was supported over a ring fabricated using mild steel flat of 50 × 5 mm. Four legs of flat plates (50 × 5 mm) were welded to the ring. The rings were mounted over the main frame at an angle of 105.5° from the horizontal.

The metering mechanism was supported over four UCP bearings. The bearings were mounted over the main frame at a height of 50 mm from the top surface of the frame. A square section pipe of 50 × 50 × 200 mm was used between each bearing and the main frame. The containment tray was mounted using the adjustable legs. The overall dimensions of the developed machine were 1980 × 710 × 1447 mm

### Stepper Motor Selection

The stepper motor was selected based on the study conducted for maximum torque requirement during the fertilizer metering.[17] Considering the maximum torque of 4.5 N.m for running the fertilizer metering mechanism, a stepper motor, Nema 34 with torque 8.5 N.m was selected for the machine, taking a factor of safety 1.9.

### Plant Sensing and Actuation Unit

It is very important for a spot fertilizer dispensing unit to detect the target plant where fertilizer needs to be applied. Sensors available for the non-contact detection of plant were reviewed and compared for

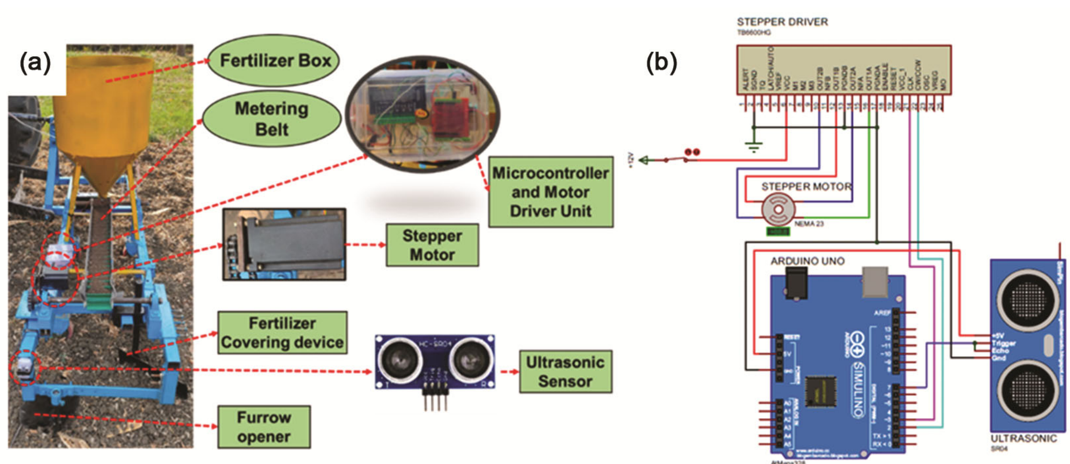


Fig. 4 — Spot granular fertilizer dispensing machine: (a) Components, and (b) Circuit of the sensing and actuation system

the specifications and limitations. Sound wave based ultrasonic sensors are reliable compared to optical type IR sensors for detection of plants in outdoor conditions because IR sensors give noise signals due to sunlight which is not a problem in ultrasonic sensors. Ultrasonic Distance Sensor (HC-SR04) which works in any lighting condition for a range of 20 to 3000 mm was selected for plant detection. Arduino Uno (ATMega 328) microcontroller having 14 digital i/o pins, 6 analog input pins, 16 MHz IC and 32 KB memory was used for storing and executing the program (Fig. 4b). Actuation part of the machine consists of a stepper motor, stepper driver, push button and battery. Arduino UNO and stepper motor driver were powered using 12 V battery used for agricultural tractors. A push button was connected to digital pin $D_4$ for initially filling the fertilizer in metering belt grooves.

Ultrasonic sensor was used for measuring the distance of plant when plant stem comes in the way of ultrasonic signals. The microcontroller was programmed to calculate the time between trigger and echo of sound wave. The distance was calculated using the velocity of sound waves in air (332 $m.s^{-1}$) and the time between trigger and echo (Eq. 7).

$$\text{Distance} = \text{Speed of sound} \times \text{time} \times 0.5 \quad \dots (7)$$

**Fertilizer Dispensing Algorithm**

The microcontroller was programmed in three phases (Fig. 5). The first phase consisted of the input variable to the microcontroller i.e. plant spacing, fertilizer application rate and maximum allowable distance of plant from the sensor. The second phase comprised of the plant detection sequences. The third phase included the actuation mechanism for fertilizer dispensing.

***First Phase***

During the execution of the first phase of the algorithm, the basic parameters were entered in the program such as metering belt groove capacity, groove spacing, fertilizer application rate per plant and the number of steps required to fill the metering belt. The microcontroller program in first phase was executed only once for a set of variables.

***Second Phase***

The second phase of the algorithm executes the plant detection while the machine travels in the forward direction. The sensor continuously monitors the distance of the plant and compares whether it was less than or equal to 500 mm. If the distance between the sensor and the plant is beyond 500 mm, it continues to move forward without dispensing the fertilizer.

***Third Phase***

The third phase start as soon as the sensor detects a plant in the vicinity of 500 mm. microcontroller sends a signal to the stepper motor driver to rotate the

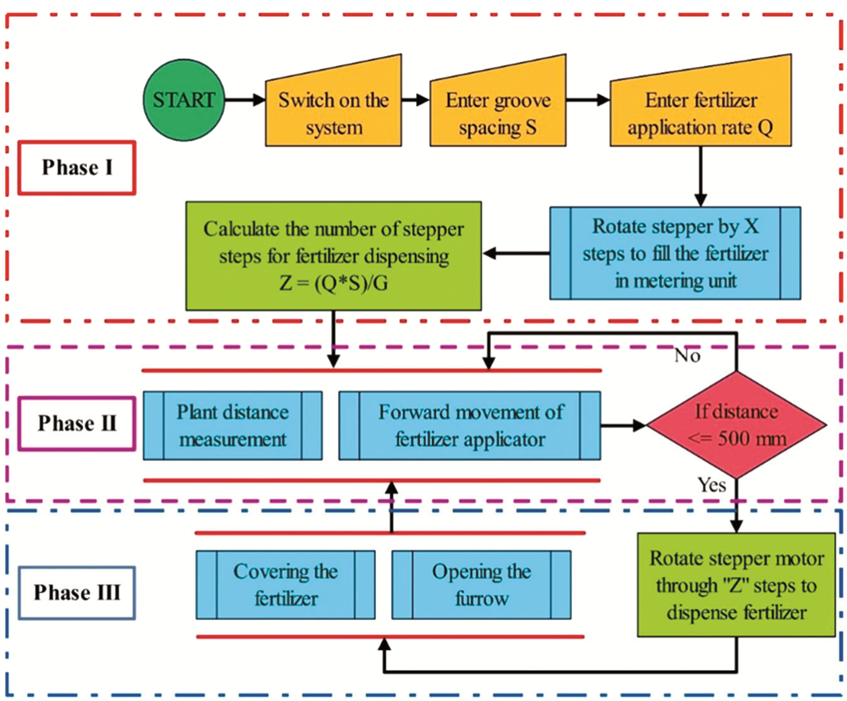


Fig. 5 — Algorithm for plant sensing and fertilizer dispensing system

stepper motor through the fixed number of steps. A small trench was made by furrow opener where fertilizer to be dispensed and covered using the furrow covering device. After the completion of fertilizer dispensing, the sensor again starts the searching of the next target plant.

The loop will be executed for plant sensing and actuation of stepper motor until the system is switched off manually.

#### Laboratory Experimentation

An optimization study was conducted using full factorial with Completely Randomized Design (CRD) to obtain design values for development of spot fertilizer dispensing machine in laboratory. Paired t-tests were applied for comparing the means of band spacing and measured application amount with plant spacing and actual application amount, respectively. Green plants with 3 to 4 small branches were anchored in soil bin according to experimental plan (Table 1). The machine was mounted on soil bin trolley. The forward speed of machine was maintained by the soil bin control panel. The desired speed of metering belt was obtained by changing the microcontroller program. Three customized green PVC metering belts with required groove volume were used as per the experimental plan. The machine and operational parameters selected for the study along with their levels are shown in Table 1.

A total of 108 experimental combinations were replicated 5 times and depended parameters were measured.

## Results and Discussion

The laboratory experiments were conducted to optimized the machine and operational parameters based on fertilizer placements, band length and band width (Table 1). The target was to apply the fertilizer near plant in a sort band of 20 to 25 cm band length and 5 to 10 cm away from the plant having a band width of 10 to 15 cm. The data was analysed using Design Expert 13.0 software. Linear model was applied and the results obtained are given in Table 2.

#### Effect of Independent Parameters on Band Length

Band length was significantly affected by forward speed of the machine. Because, the distance travelled during the actuation time of fertilizer dispensing changes from 18.15 to 34.24 cm (Fig. 6). This difference in distance significantly affects the band length; results are in confirmation with researcher.[8] Whereas, there was no significant difference in band

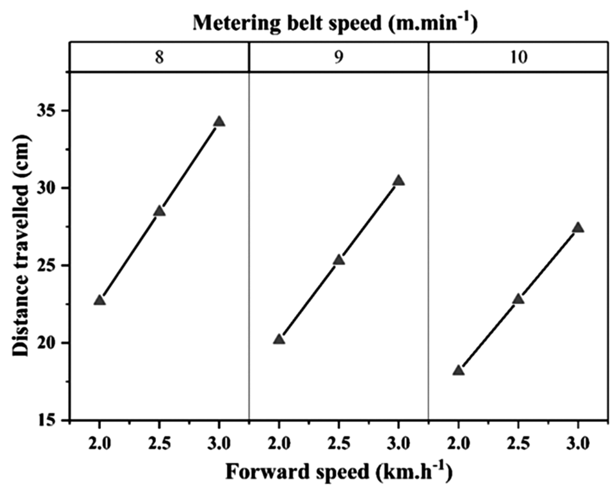


Fig. 6 — Change in distance travelled during actuation of fertilizer dispensing

Table 1 — Details of independent and dependent parameters

| Sr. No. | Independent parameters | Levels | Dependent parameters |
|---|---|---|---|
| 1 | Metering belt groove volume, $cm^3$ | 50, 100, 150 | 1. Band length |
| 2 | Metering belt speed, $m.min^{-1}$ | 8, 9, 10 | 2. Fertilizer placement inside |
| 3 | Plant spacing, cm | 45, 60, 75, 90 | 3. Fertilizer placement outside |
| 4 | Forward speed, $kg.h^{-1}$ | 2, 2.5, 3 | 4. Band width |

Table 2 — ANOVA table for all dependent variables

| Source | F-value | | | |
|---|---|---|---|---|
| | Band length | Fertilizer placement inside | Fertilizer placement outside | Band width |
| Model | 5.8** | 2.52** | 9.91** | 4.51** |
| Groove volume | $0.0127^{NS}$ | $3.6^{NS}$ | 24.53** | 11.58** |
| Plant spacing | $0.0144^{NS}$ | $3.07^{NS}$ | $0.0734^{NS}$ | $3.1^{NS}$ |
| Belt speed | $1.41^{NS}$ | 4.06* | 11.09** | $2^{NS}$ |
| Forward speed | 21.75** | $0.8787^{NS}$ | $3.95^{NS}$ | $1.34^{NS}$ |
| Mean | 22.04 ± 0.183 | 10.79 ± 0.163 | 23.39 ± 0.166 | 12.60 ± 0.1341 |
| CV % | 7.93 | 14.37 | 6.39 | 10.40 |

* Significant at 5% level, ** significant at 1% level and $^{NS}$ non-significant

length for groove volume, plant spacing and metering belt speed.

**Effect of Independent Parameters on Fertilizer Placement Inside**

Fertilizer placement near the plant changes significantly with metering belt speed. The start point of the trajectory ($e_t$) of the fertilizer falling from the metering belt changes with tangential velocity of the metering belt which can be calculated using Eq. 8.[18] This change in trajectory affects the lateral distance of the fertilizer placement.

$$\frac{V_S^2}{gr} = \cos\gamma \qquad \ldots (8)$$

where, $V_S$ = Linear velocity of metering belt ($m.s^{-1}$), g = acceleration due to gravity ($m.s^{-2}$), r = effective radius of the material conveyed (m) and $\gamma$ = Angle for which fertilizer is in intact with belt (degree).

**Effect of Independent Parameters on Fertilizer Placement Outside**

The effect of groove volume and metering belt was highly significant on fertilizer placement outside. The change in groove volume was achieved by changing the groove height thus changing the height of fertilizer above metering belt. Therefore, it changes the trajectory of fertilizer dropping off the metering belt. Similarly, the metering belt speed affects the trajectory of fertilizer off the belt thus fertilizer placement outside. The effect of plant spacing and forward speed of machine on fertilizer placement outside was non-significant ($p$ >0.05).

**Effect of Independent Parameters on Band Width**

Band width is the difference between fertilizer placement inside and outside. The effect of groove volume was significant on band width at 1% level of significance. This was due to the dropping off of different amount of fertilizer in same time duration, which caused more lateral spread than longitudinal. All other factors were not significantly influencing the band width. In case of metering belt speed both fertilizer placement inside and outside were significantly affected ($p \le 0.05$, and $p \le 0.01$, respectively) but both were changing similarly. Therefore, the effect of metering belt speed was found non-significant at 5% level of significance.

The maximum deviation in band length and band width from the target values were 1.41 and 0.47 cm, respectively (Fig. 7). The minimum and maximum

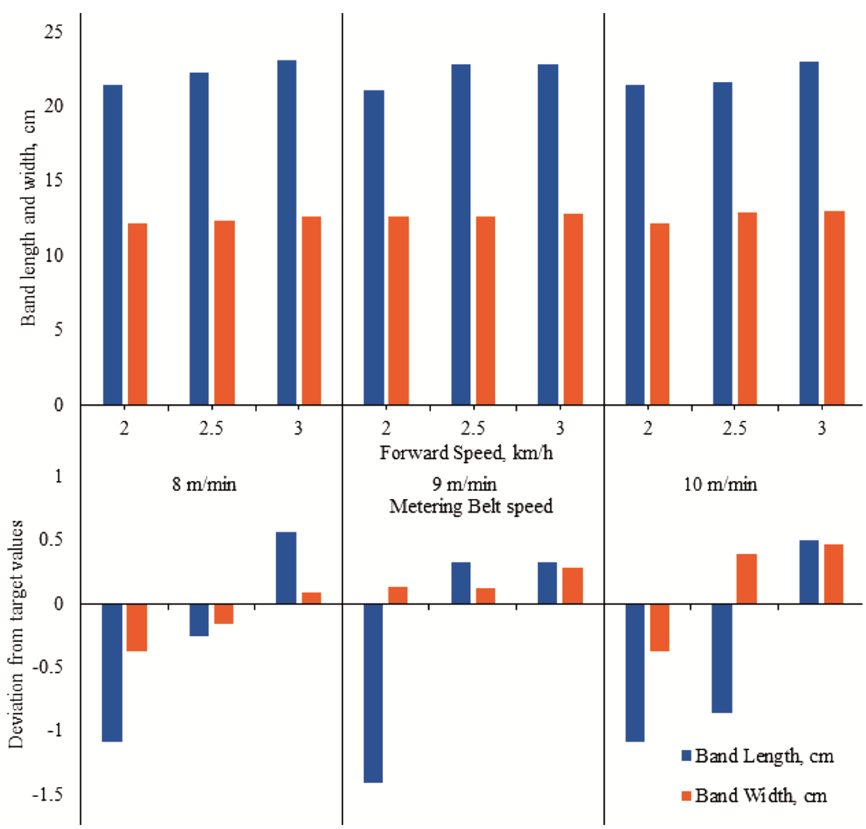


Fig. 7 — Deviation in band length and band width from target values

values of fertilizer placement inside, outside and band width were observed 6.8, 16.75, 19.5, 26.75, 8.75, and 16.5 cm, respectively (Fig. 8).

Paired t-test showed that there was no significant difference was found between plant spacing and band spacing for all experimental plant spacings (45, 60, 75 and 90 cm) (Table 3). This was due to the maximum time required for plant sensing and fertilizer dispensing (0.413 s at 8 $m.min^{-1}$ metering belt speed) was less than the minimum time available between successive plants (0.6 s at 45 cm plant spacing and 3 $km.h^{-1}$ forward speed).

Paired t-test showed that there was no significant difference ($p$>0.05) between required application amount and measured application amount per plant for all belt groove volume levels (50, 100 and 150 $cm^3$) (Table 3). Unlike other studies,[8,9] forward speed has no significant effect on fertilizer application amount in our case.

**Optimization and Validation**

Optimization of the operational and machine parameters was done using the numerical optimization tool in Design expert software (version 13.0) to get the target value of band length, band width, fertilizer placement inside and outside of 22.5, 12.5, 10 and 22.5 cm, respectively. The optimum values of independent parameters groove volume; plant spacing, belt speed and forward speed were 50 $cm^3$, 78.4 cm, 8.743 $m.min^{-1}$, and 2.724 $km.h^{-1}$, respectively. The optimum values of dependent parameters for optimum independent parameters were 22.5, 12.25, 9.95 and 22.5 cm for band length, band width, fertilizer placement inside and fertilizer placement outside, respectively with a desirability of 0.971. The laboratory experiment was conducted using optimized values of independent parameters and the paired t-test was applied for the comparison of dependent parameters to validate the result. The experimental values for optimized independent parameters were 22, 12, 10 and 22 cm for band length, band width, fertilizer placement inside and outside, respectively. There was no significant difference between experimental and predicted values of the dependent parameters.

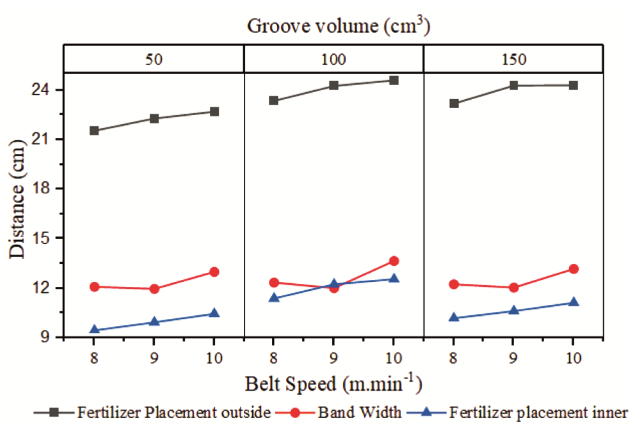


Fig. 8 — Variation in fertilizer placement with metering belt speed

**Field Evaluation**

The developed spot fertilizer applicator was evaluated with optimized operational parameters in guava (2 × 2 m) and mango (3 × 3 m) field in ICAR-CIAE, Bhopal. The area under guava and mango field were 0.1 and 0.2 ha, respectively during field evaluation. The machine was operated at three forward speeds 2, 2.5 and 3 $km.h^{-1}$ and replicated thrice.

The machine was evaluated in terms of fertilizer application amount, field capacity and field efficiency. The results were analysed using full factorial CRD in Design expert software. The lack of fit for the selected model was non-significant with $R^2$ values above 0.8. Therefore, the selected model was adequate. The forward speed of the machine had no significant effect on fertilizer application amount. The mean fertilizer application amount was 200.33 g (Fig. 9a). The fertilizer application amount decreased from 202 to 198 g with increase in forward speed from 2 to 2.5 $km.h^{-1}$. Further increase in forward speed from 2.5 to 3 $km.h^{-1}$ increased the application amount 198 to 200 g.

The effective field capacity of the machine was measured at three different forward speeds of 2, 2.5

Table 3 — Paired t-test for comparison of plant spacing with band spacing and required application amount with measured application amount

| Parameter | Spacing, cm | | | | Application amount, g | | |
|---|---|---|---|---|---|---|---|
| | 45 | 60 | 75 | 90 | 50 | 100 | 150 |
| Mean | 44.7 ± 0.23 | 60.62 ± 0.39 | 75.33 ± 0.30 | 90.3 ± 0.26 | 49.61 ± 0.34 | 99.08 ± 0.32 | 149.61 ± 0.31 |
| CV % | 6.08 | 7.61 | 4.69 | 3.33 | 4.15 | 1.92 | 1.27 |
| t-value | 1.266 NS | −1.567 NS | −1.097 NS | −1.145 NS | 1.133NS | 1.65NS | 1.227NS |

* Significant at 5% level, ** significant at 1% level and NS non-significant.

Table 4 — Comparison between developed fertilizer applicator and available mechanical sensing type fertilizer applicators

| Parameter | Developed sensor-based spot fertilizer applicator | Mechanical sensing-based spot Grape Vineyard fertilizer applicator[9] | Spot neem coated fertilizer applicator for cotton crop[8] |
|---|---|---|---|
| Sensing method | Ultrasonic Sensor | Lever and spring | Lever and spring |
| Metering mechanism | Microcontroller based grooved belt with stepper motor | Ground wheel based fluted roller | Ground wheel based fluted roller |
| Effect of forward speed on fertilizer applied per plant | Not significant effect of speeds 2, 2.5 and 3 km.h$^{-1}$ | Significant effect of speeds 2, 2.5 km.h$^{-1}$, and 3, 3.5, 4 km.h$^{-1}$ | Significant effect of speeds 1.57, 2.04, and 2.5 km.h$^{-1}$ values. |
| Plant detection and fertilizer dispensing time | 0.33 to 0.41 s | 0.9 to 0.95 s | 0.8 to 0.9 s |
| Variation in fertilizer application per plant | 1.27–4.15% | 15–20% | 12.16–20.42% |

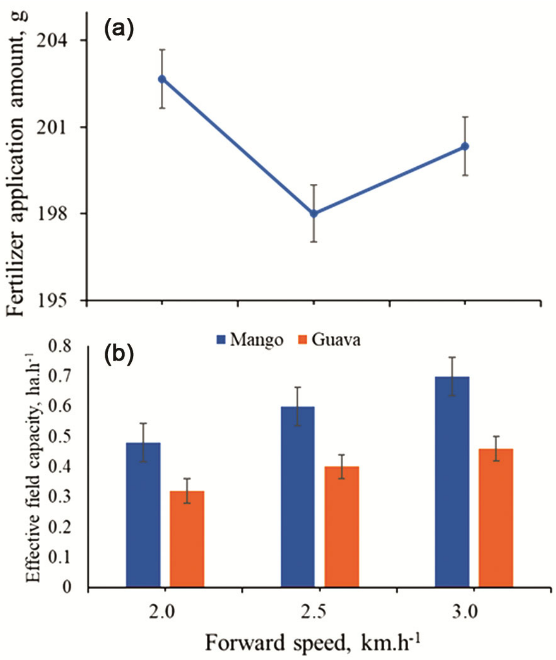


Fig. 9 — Variation in: (a) fertilizer application amount, and (b) effective field capacity with forward speed

and 3 km.h$^{-1}$. The effective field capacity of the machine increased from 0.48 to 0.7 ha.h$^{-1}$ and 0.32 to 0.46 ha.h$^{-1}$ with increase in the forward speed during field evaluation in mango (spacing = 3 m) and guava (spacing = 2 m) orchards, respectively (Fig. 9b). The mean values of effective field capacity were 0.59 and 0.39 ha.h$^{-1}$ during field evaluation in mango and guava orchards, respectively. The average effective field efficiency and mean application rate were 79.3% and 200.33 ± 0.85 g.plant$^{-1}$, respectively for a target application rate of 200 g per plant in guava and mango orchards.

The developed sensor based spot fertilizer applicator is compared with the previously developed mechanical sensing based spot fertilizers (Table 4). The parameters of existing spot fertilizer applicators were obtained from the available literatures.

The machine offers the potential to reduce fertilizer usage by 20 to 50% when compared to conventional fertilizer broadcasting. Additionally, it significantly reduces both time and cost, with savings of 90% and 30%, respectively, compared to the manual ring basin method. The machine's anticipated impact could lead to a substantial reduction of 25.23 thousand tonnes of fertilizer usage in India, assuming a 5% improvement over current practices.

## Conclusions

An automatic plant detection, precise fertilizer metering and accurate fertilizer placement machine was developed which is fully orchard compatible and can be attached to the tractors. The laboratory evaluation showed variations in fertilizer placement accuracy and application rate per plant in the range of 5–10%, and 5–8%, respectively. Band length significantly increased (between 18.0 to 26.4 cm) with increase in forward speed (2 to 3 km.h$^{-1}$). Groove volume and metering belt speed significantly affected the lateral fertilizer placement within acceptable limits. The developed plant sensing based; automatic spot fertilizer applicator has three times less variation (5 to 8%) in amount of fertilizer applied per plant in comparison to the mechanical sensing-based ground wheel powered metering spot fertilizer applicators. The developed spot fertilizer applicator shows promising future for the fertilizer management in orchards. The suitability of the developed spot fertilizer applicator in field crop is needed to be identified.

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