Spanish Journal of Agricultural Research
22 (1), e0201, 14 pages (2024)
eISSN: 2171-9292
https://doi.org/10.5424/sjar/2024221-20185
INIA-CSIC

RESEARCH ARTICLE

OPEN ACCESS

Development and evaluation of a machine vision-based cotton fertilizer applicator

Arjun Chouriya, Edathiparambil V. Thomas, Peeyush Soni*, Vijay K. Patidar and Laxmikant Dhruw

Indian Institute of Technology Kharagpur, Kharagpur, 721302 India

***Correspondence** should be addressed to Peeyush Soni: soni@iitkgp.ac.in

Abstract

Aim of study: To develop and assess a cotton fertilizer applicator integrated with a Machine Vision Based Embedded System (MVES) to achieve precise and site-specific fertilization.

Area of study: The investigation was performed in the Indian Institute of Technology, Kharagpur.

Material and methods: The MVES included a cotton detection system with a web camera, processor (computer), and python-based algorithm, and a fertilizer metering control unit with a stepper motor, motor driver, power supply, and microcontroller. The python-based algorithm in the computer predicts the presence (or absence) of cotton plants, whenever an input image is received from the camera. Upon cotton detection, it transforms into a Boolean signal sent to the microcontroller via PySerial communication, which instructs the motor to rotate the metering unit. Motor adjusts the speed of metering unit based on machine speed measured through a hall sensor, ensuring site-specific delivery of metered fertilizer A developed lab setup tested the MVES, experimentally examining performance indicators.

Main results: The MVES obtained a MAPE of 5.71% & 8.5%, MAD 0.74 g/plant & 1.12 g/plant for urea and DAP (di-ammonium phosphate), respectively. ANOVA revealed no statistically significant effect of forward speed on the discharge fertilizer amount ($p>0.05$). For urea, discharge rates ranged from 1.03 g/s (at 10 rpm, 25% exposure length of metering unit) to 40.65 g/s (at 100 rpm, 100% exposure). DAP ranged from 1.43 to 47.66 g/s under similar conditions.

*Research highlights***:** The delivered application dosage conformed the recommended dosage. The developed MVES was reliable, had a quick response, and worked properly.

Additional key words: fertilizer application; electronic drive system; image processing; micro-granular fertilizer; plant detection

Abbreviations used: DAP (di-ammonium phosphate); MAD (mean absolute deviation); MAPE (mean absolute percent error); MVES (machine vision based embedded system); VFD (variable frequency drive).

Citation: Chouriya, A; Thomas, EV; Soni, P; Patidar, VK; Dhruw, L (2024). Development and evaluation of a machine vision-based cotton fertilizer applicator. Spanish Journal of Agricultural Research, Volume 22, Issue 1, e0201. https://doi.org/10.5424/sjar/2024221-20185

Received: 20 Jan 2023. **Accepted**: 08 Nov 2023. **Published**: 09 Jan 2024.

Introduction

Cotton (*Gossypium* spp.), also known as the 'king of fiber' and 'white gold', is one of the most important cash crops in India (Konduru et al., 2013), where it occupies ~$12.15 \cdot 10^6$ ha, which is the 36% of the world's area under cotton cultivation. Production of cotton during 2020-21 was 27.60 million bales. However, India's average cotton yield is 439 kg/ha, which is lower than the global average yield of 759 kg/ha (USDA, 2021). Eventually, Indian farmers receive a low income per hectare. The yield of the cotton crops depends mainly on intercultural operations, timely fertilizer application, rainfall, soil and proper irrigation management practices (Hussein et al., 2011; Yang et al., 2012; Thorp et al., 2014; Rakkar & Blanco, 2018). Fertilization is an essential and effective method to amend soil properties and increase crop production and yield; and its quality greatly depend on the fertilizer (Reddy & Boykin, 2010; Abdel-Aziz et al., 2016; Hou et al., 2021). Cotton production and quality are increased by increasing the nitrogen rate per hectare (Blumenthal et al., 2008; Liu et al., 2021). Applying fertilizer to the crops should be done at the appropriate rate, as it can be expensive and have detrimental effects on the environment and soil when used excessively (Zhu & Chen, 2002; Murray et al., 2006; Evanylo et al., 2008; Shakoor et al., 2018).

In recent years, various designs of fertilizer applicators have been developed, especially to handle granular fertilizers. A spreader broadcasts the fertilizer in a small field but it is very difficult to maintain uniformity in delivering fertilizer over the entire field (Yildirim, 2006). Similar findings have also been reported by several researchers (Van Liedekerke et al., 2008; Jotautiene et al., 2022; Zinkeviciene et al., 2022). Many scientists (Chandel et al., 2016; Alameen et al., 2019; May & Kocabiyik, 2019) developed a variable-rate fertilizer applicator with an electronically-controlled fluted roller metering mechanism. But, these developed metering mechanisms are employed for the continuous application of fertilizer at the time of sowing with seed drilling. The variations in the discharge rate are adjusted by changing exposed length of the fluted roller type metering unit. Seenauth (2003) developed a fertilizer applicator to spread granular fertilizer based on a broadcasting method with many challenges such as non-uniformity of fertilizer application, wastage of fertilizer, and eventually led to increased growth of weeds. Furthermore, an injector type (non-continuous operation) and a push single type row (continuous operation) fertilizer broadcasters were designed by researchers. However, it was revealed that labor requirement in non-continuous operation was higher than in continuous operation because of manual operation of these fertilizer applicators (Wohab et al., 2017). Xingsheng et al. (2011) developed a cotton fertilizer machine which delivered the fertilizer after drilling near the plant; however, this is time-consuming, and labour intensive. Later on, a lightweight organic fertilizer distributor was developed by Hu et al. (2020) for continuous spreading of granular fertilizer. An electronic circuit with the appropriate algorithm measured 10% deviation between the actual fertilizer rate and the target fertilizer rate. The difficulty was that the fertilizer rate depends on the forward speed. Fazhi et al. (2022) developed a mechanical fertilizing machine to deliver fertilizer at specific location by drilling. However, the biggest challenge with this machine is that the fertilizer device must be stopped near every plant, hence, does not support continuous operation. Kim et al. (2008) developed a variable rate granular fertilizer applicator using fluted roller metering unit for rice crop in continuous manner. The motor controls the speed of the metering unit by the forward speed of fertilizer applicator. Within its operational speed range, the precision of fertilizer distribution spanned from 81.9% to 97.4%.

The application of image processing represents a prevalent method for target detection in precision agriculture. Berenstein & Edan (2017) created a collaborative grape cluster sprayer for site-specific spraying; they created a target identification algorithm using basic color thresholds which reduced sprayed material by 50%. Oberti et al. (2016) examined a machine vision-based disease detection robot using the red-green-near infrared channel of multispectral imaging for precision spraying; the developed algorithm decreased pesticide amount by 65-85% compared to the traditional method. Xiuyun et al. (2019) developed ZigBee based liquid fertilizer applicator using machine vision to measure and regulate the liquid fertilizer with 99.52% applicator accuracy. Tewari et al. (2020) developed an image processing algorithm which estimated real-time disease severity to enable chemical application adjustments; the system reduced chemical use by 33.88% as compared to the conventional method. Similar type of study using image processing technique has been done by other researchers (Tackenberg et al., 2016; Sudkaew & Tantrairatn, 2021). Other researchers analysed different methods of fertilizer application and revealed that the maximized cotton yield, lint quality, and maximum utilization of fertilizer correspond to the effectiveness of fertilizer application/placement method (Bakhtiari, 2014; Jamro et al., 2016; Nkebiwe et al., 2016). So, there is a need to upgrade fertilizer applicators' placement method.

Generally, the broadcasting and direct placement method are used to apply the fertilizer. The broadcasting method of fertilizer application is associated with various operational challenges such as high discharge rate, non-uniform application of fertilizer, wastage of fertilizer, and eventually led to increased growth of weeds (Rahman & Zhang, 2018). Manual placement of fertilizer is good for crop effective application but it is labor-intensive, time-consuming, and leads to create posture-related problems for laborers such as back muscle pain, etc. (Pan et al., 2017). The preceding literature indicates that the utilization of image processing along with electronic components works effectively for liquid spraying, and could be employed for granular fertilizer application through plant detection. The majority of granular fertilizer applicators utilize the broadcasting method of fertilization, while placement method-based applicators are used intermittently rather than continuously. Therefore, there is a need for automation of placing granular fertilizer in the cotton field; leading to design and development of such an applicator that can do such task with precision and effectiveness in order to reduce wastage of fertilizer, offer time-saving, and reduces the overall cost of fertilizer application. This research was carried out to design and develop a precise fertilizer applicator, especially to cotton field.

Material and methods

The machine vision technique is used in this research to detect cotton plants based on its color. The presence (or absence) of cotton plants is converted into a Boolean signal (either 1 or 0) and sent to the microcontroller to

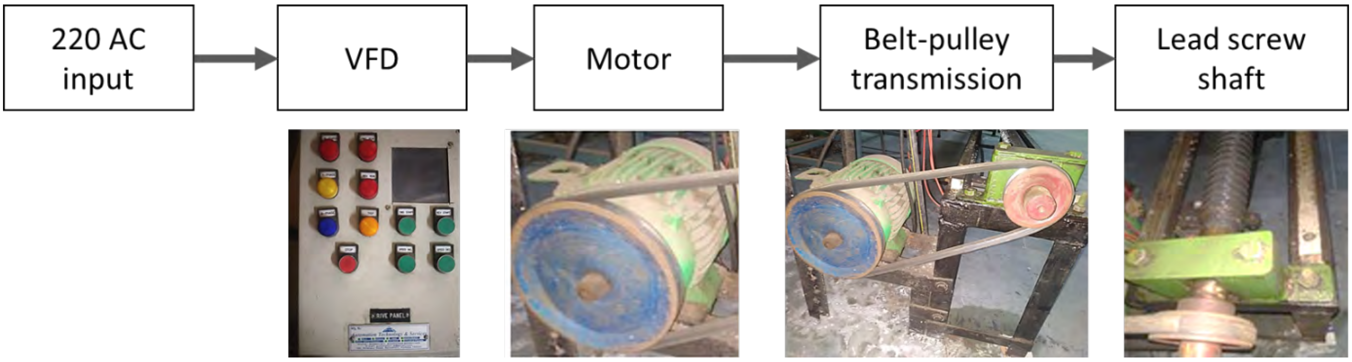


Figure 1. Flow chart of the power transmission system. VFD: variable frequency drive.

control the fluted roller metering unit through motor. The detected and non-detected plants are represented by 1 and 0 respectively. The fluted roller delivers fertilizer to the cotton plants as per the received signal from microcontroller. The fertilizer application will continue as long as the signal remains active. The duration of the signal of the detected plant depends on the longitudinal length of the canopy. When all cotton seeds are sown simultaneously, the theoretical longitudinal length of canopy remains uniform for all plants. Consequently, all plants receive an equivalent amount of fertilizer. However, in the next doses of fertilizer application, the canopy's longitudinal length increases. Thus, the stepper motor's duration will increase, leading to greater fertilizer delivery. To maintain consistent fertilizer quantities across all plants for next stage of fertilization, the fertilizer amount is reduced by decreasing the exposure length of fluted roller metering unit. Farmers can also adjust the amount they want to deliver according to their own preferences by changing the exposure length of fluted roller. A special laboratory setup was also fabricated to evaluate performance of the developed cotton fertilizer applicator under controlled conditions. The developed setup encompassed power transmission unit, plant conveying unit, fertilizer hopper with metering unit, and machine vision-based embedded system.

Power transmission system

A variable frequency drive (VFD-MS300, 1HP 0.75KW 230V 4.8A, Delta Electronics, India) controlled a 220V AC motor, which in turn, powered the lead screw shaft through belt and pulley transmission. The lead screw shaft transported the crop holding platform through two rollers and the

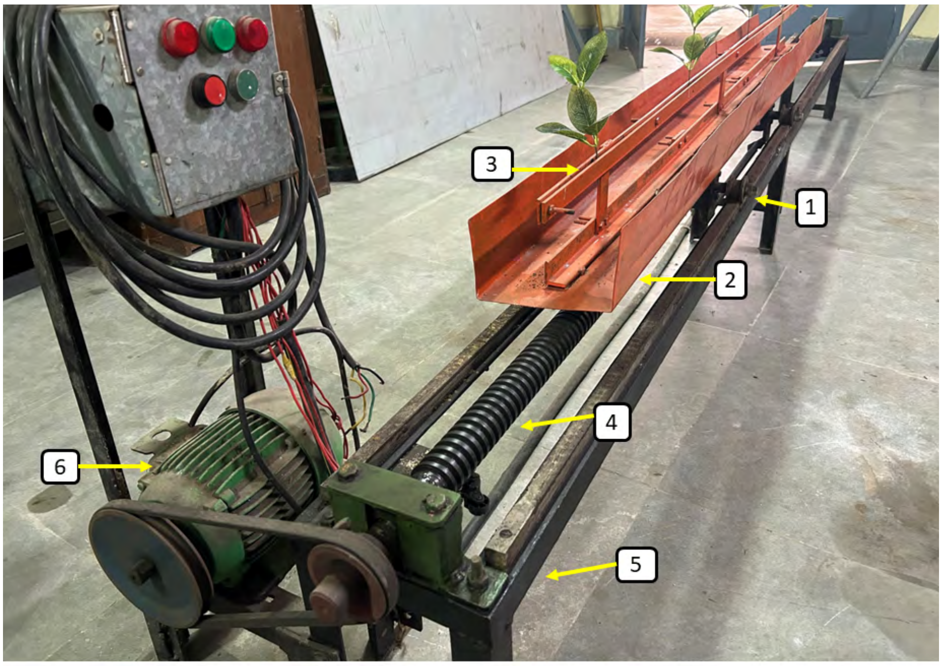


Figure 2. Plant conveying system: 1, roller; 2, crop holding platform; 3, crop holding unit; 4, lead screw; 5, frame; 6, motor.

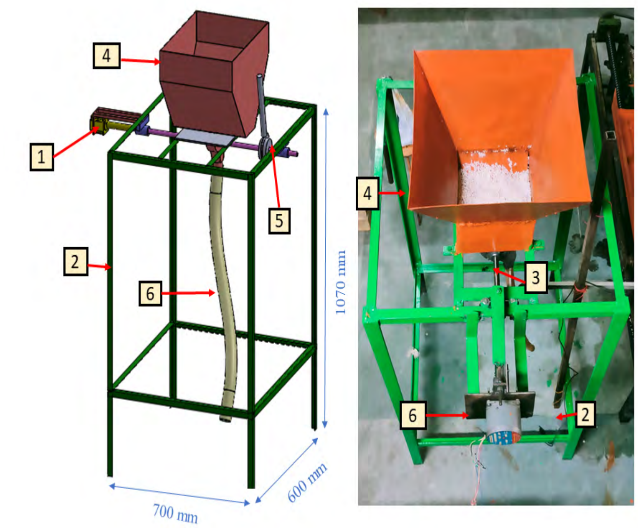


Figure 3. Schematic diagram of fertilizer hopper: 1, motor; 2, frame; 3, fertilizer metering unit; 4, hopper; 5, shifting lever; 6, fertilizer tube.

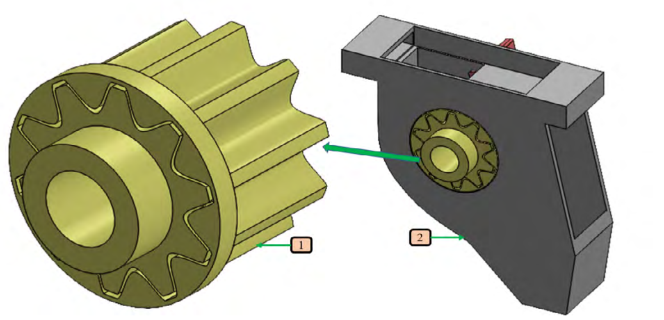


Figure 4. Fluted roller metering unit: 1, fluted roller; 2, metering shell.

speed controlled with the lead screw rpm; the flow chart of the power transmission is shown in Fig. 1. The maximum and minimum linear velocity of plant conveying platform were 0.2 and 1.0 km/h and corresponding rotational speed of lead screw 263 rpm and 1313 rpm, respectively.

Plant conveying unit

The plant conveying unit (Fig. 2) carried cotton plants from one end to another end of a frame (3160 mm length × 220 mm width × 330 mm height). This frame was supported by legs placed equi-distant. A 12.7 mm pitch lead screw transmitted power from motor to a roller. Rollers were used to carry and axially move the crop holding platform along the lead screw when the roller is rotated. Thus, the platform could be run at a speed as desired. The rollers were fitted to a track that was mounted on the frame. The crop holding platform (1900 mm length) was mounted parallel to the axis of the threaded shaft on the frame. It was designed for holding cotton plants vertically and maintaining a desired horizontal spacing between them. The longitudinal spacing between the plants could be varied as needed.

Fertilizer hopper with metering unit

A trapezoidal-shaped hopper (Fig. 3) was designed to store the fertilizer by considering its physical properties, and to feed it to a metering unit. The hopper was welded to the frame and supported by the horizontal shaft. A fluted-roller-type fertilizer metering unit is used for the cotton fertilizer applicator, which is usually recommended for uniform distribution of fertilizer (Gurjar et al., 2017). The eight-flute metering unit (Fig. 4, 36 mm diameter, 40 mm length) was installed below the fertilizer hopper, which eventually discharged the precisely metered fertilizer into a fertilizer tube. In order to precisely control the fertilizer application rates, a 12 V DC stepper motor was used to control the fluted roller operation. The flow rate of the fertilizer depends on the exposure length of the fluted roller. The fluted roller's exposure length was adjusted by shifting the fertilizer metering shaft with a shifting lever.

Machine vision based embedded system (MVES)

The developed MVES (Fig. 5) is comprised of a cotton detection system (Fig. 6) and a fertilizer metering control unit. The cotton detection system consists of web camera, computer as a processor (8GB SSD, 8GB RAM, Intel(R) Core™ i5-7200U, Windows 10 operating system, Dell, India), and a python-based cotton detection algorithm. The fertilizer metering control unit is comprised of stepper motor, motor driver, power supply (12 volts 1.3 Ah, Exide India), microcontroller (Arduino®Uno). The python-based cotton

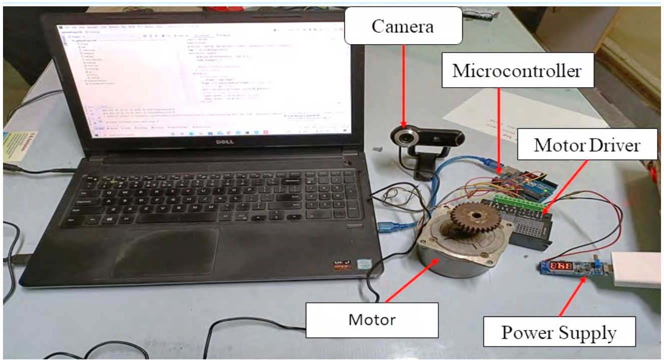


Figure 5. Developed machine vision-based embedded system.

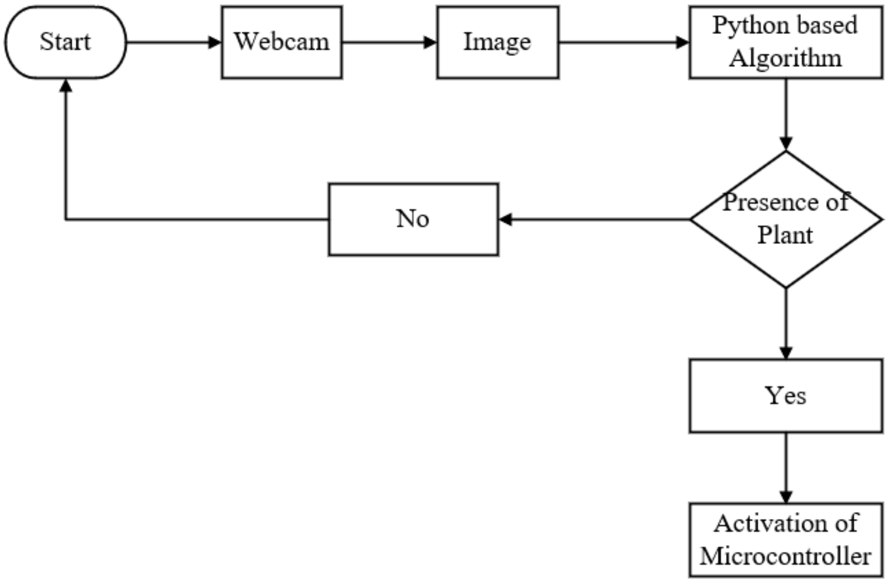


Figure 6. Flow chart of the developed cotton detection system.

detection algorithm was executed in python 3.6 environment of the computer to detect the cotton whenever images come from the webcam. Web camera was connected to the computer via USB port. The camera captured the image whenever the plant came in field-of-view of the camera, and channelled it to the computer. The executed algorithm in computer predicts the presence (or absence) of cotton plants from the input image received from the camera. Arduino®Uno and computer communicated through PySerial. When a cotton plant was detected, it was converted into a Boolean signal and sent processor to the microcontroller through PySerial communication. The microcontroller then commanded the motor to drive according to the received signal in PySerial. The motor regulated the shaft of the fertilizer metering unit in correspondence with the conveying unit's forward velocity, which was assessed using a hall effect sensor. The rotation of the fertilizer metering unit facilitated the precise delivery of fertilizer to the specified target plant.

a) Development of image processing-based algorithm

The image processing algorithm was developed using the open-source computer vision library (OpenCV) and python language (v3.6). The algorithm is described in a flow chart as shown in Fig. 7.

— *Image capture.* Real-time images were continuously captured by the camera at the rate of 30 frames per second. Each image was saved by the algorithm developed in PyCharm 2018.3.1 (JetBrains s.r.o, IntelliJ Software, Russia).

— *Extracting each frame.* Each frame was extracted by executing the imgaeObj.read() function from the captured image.

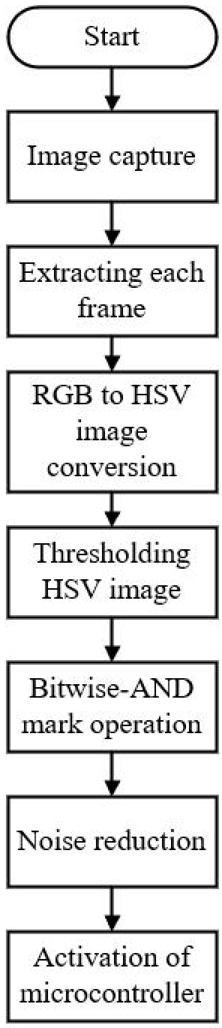
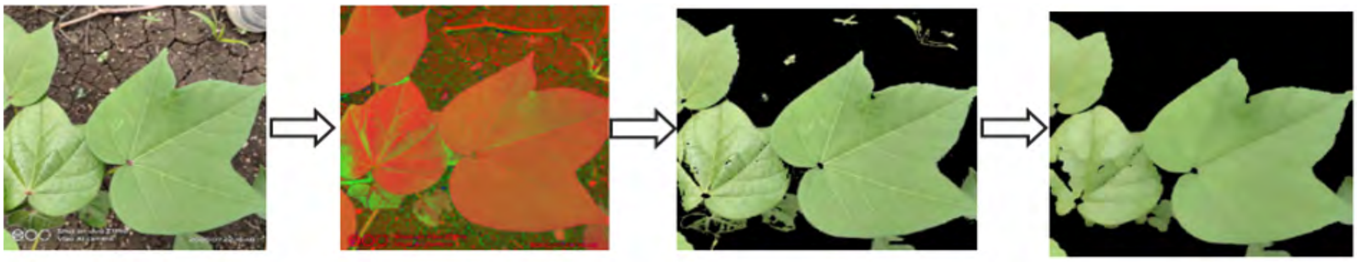


Figure 7. Flow chart of the developed image processing algorithm.



(1) (2) (3) (4)

Figure 8. Stages of different image segments to detect cotton plant: (1) original image; (2) HSV image; (3) threshold image; (4) image after noise reduction.

— *RGB to HSV image conversion.* The RGB image captured with the camera has a resolution of 960 × 720 pixels. The RGB format denotes the intensity of the three primary colors that comprise it, i.e., red, green, and blue. Brightness of the colour is represented by a value ranging from 0 to 255. RGB image format is generally less preferred for image segmentation due to not uniformity. The HSV (hue, saturation, value) color space model is used for segmentation (Ganesan & Rajini, 2014). Based on the physical characteristics of cotton plant leaves, the minimum and maximum values of HSV were established. Numerous experimental trials were conducted to ascertain a range of values across diverse conditions, specifically targeting the optimal value for precise and distinct detection of cotton plants. Notably, the HSV settings for the lower green boundary were set at 40, 40, and 40, while for the upper green boundary, these were configured as 70, 255, and 255 respectively. Through meticulous refinement, it was determined that the cotton plants were distinctly and sharply detectable at the established minimum and maximum HSV values.

— *Thresholding HSV image.* Thresholding was used for separating an object from its background on the basis of the range of HSV. To get only the green color, thresholding was performed on the HSV image.

— *Bitwise-AND mark operation.* Bitwise operations are used for extracting essential features in the image and help in image masking. The Bitwise-AND mark operation was used to determine the intersection of two images that distinguishes the cotton plant image from its background.

— *Noise reduction.* The noise from the image was reduced by performing opening morphological operation to enhance the quality of the image (Said et al., 2016). Using the same structural element for both processes, the erosion operation was performed to remove the small blob from an image; then the dilation operation was executed to increase the size of foreground objects or joining broken parts of image (Tzionas et al., 2005; Eq. 1):

$$(A \circ B = (A \ominus B) \oplus B) \tag{1}$$

where, A-original image, B-structure element, o, ⊖ and ⊕ show the opening, erosion, and dilation morphological operation respectively.

— *Activation of microcontroller.* The image with enhanced quality was received after the morphological operation. The presence (or absence) of cotton plants is converted into a Boolean signal (either 1 or 0) and sent to microcontroller to control the fluted roller metering unit through motor. The detected and non-detected plant are represented by 1 and 0 respectively. An example of the different stages in image processing is presented in Fig. 8.

b) Fertilizer metering control unit

It is comprised of a 12 V DC stepper motor, motor driver (TB6600, Unimech Engineering operation, Mumbai, India), power supply, and microcontroller. The fertilizer metering unit's rotation is triggered by the stepper motor when a detected signal is received from the microcontroller. The rotation of the fertilizer metering unit is adjusted in accordance with the forward speed of the conveying unit. The forward speed of conveying unit is measured through a hall effect sensor. The rotation of fertilizer metering unit delivers fertilizer to the target plants through fertilizer tube. A two-way ANOVA was performed to analyse the effect of forward speed and exposure lengths on the fertilizer application.

c) Control function calibration

In order to make this system perform accurately, the speed of the fertilizer metering unit shaft (i.e., the stepper motor) must be controlled in accordance with forward speed of the fertilizer applicator (i.e., crop conveying unit). These real-time adjustments control the quantity of fertilizer to match the recommend dose (pre-set). The forward speed (V, mm/s) of the crop conveying unit is measured through a hall sensor:

$$V = \frac{P \times N_L}{60} \tag{2}$$

$$N_L = \frac{N \times 60}{T \times n} \tag{3}$$

where P: pitch of lead screw, mm; N_L: lead screw speed, rpm; N: number of pulses received by microcontroller; T: time, s; n: number of the installed magnet.

After measuring the forward speed of the crop conveying unit, it is necessary to establish the relationship between it and the rotational speed of the stepper motor. The time required (t) to complete the fertilization dropping length is:

$$t = \frac{L}{P \times N_M} \quad (4)$$

where N_M: stepper motor speed, rpm; L: fertilization dropping length, mm.

Li et al. (2016) established the relation between the revolution of the stepper motor and fertilizer rate Q (g/min):

$$Q = kN_M + b \quad (5)$$

where k and b are the constant, Q and N_M is a one-to-one relationship.

$$\text{Flow rate } Q = \frac{q \times P \times N_L}{L} \quad (6)$$

where q: quantity of fertilizer, g. From Eqs. (5) and (6):

$$N_M = \frac{q \times P \times N_L}{k \times L} - b \quad (7)$$

$$N_M = \frac{q \times V}{k \times L} - b \quad (8)$$

Eq. (5) establishes a relation between the rotational speed of the stepper motor (rpm) and the forward speed of the plant conveying (mm/s). As the speed of the conveying unit changes, the speed of the stepper motor also changes correspondingly. This means for plants having same longitudinal length of canopy, the fertilizer rate will remain same as well. Calibrating the delivered quantity of fertilizer involves adjusting the stepper motor within a range of 10 to 100 rpm, alongside modifying the forward speed of the conveying unit spanning from 0.2 to 1 km/h to maintain constant fertilizer amount per plant. Krishna (2015) demonstrated that for maximum utilization of fertilizer by plant, fertilizer should be applied within a 20-cm circular band around the center of the plant. The recommended doses from numerous researchers indicate that the delivered urea and DAP amount should be 13.10 g and 5.8 g per plant respectively. The value of k and b (y = 0.2027x and y = 0.2362x for urea and DAP respectively) at 50% exposure length of the metering unit were obtained during calibration of discharge rate variation with motor speed. All the above given data are inserted in Eq. (5), and the consequent outcome is demonstrated through Eqs. (7) and (8):

$$N_M = \frac{13.10 \times V}{40.54} \quad (9)$$

$$N_M = \frac{5.80 \times V}{47.24} \quad (10)$$

Micro-granular fertilizers

Cotton crop was fertilized with several micro-granular fertilizers with distinct physical and mechanical characteristics; of which, urea and DAP (di-ammonium phosphate) were used to evaluate the performance of the developed MVES in the controlled tests. The bulk density, granular diameter, angle of internal friction, and angle of repose for both the selected fertilizers were determined as 0.705 & 0.785 g/cm^3, 4.44 ± 0.28 mm & 4.85 ± 0.29 mm, 16° & 18°, and 34.92° & 30.92° respectively. Several researchers focused on the outcome of different doses of fertilizer on the cotton yield and recommended. The recommended doses viz. 120:60:60 kg NPK/ha (Reddy & Boykin, 2010), 150:40:20 kg NPK/ha (ICAR, 2022), and 150:60:60 kg NPK/ha (Ranjith et al., 2015). To fulfil the NPK requirement of 150:40:20 per hectare with plant spacing 70 cm × 60 cm, the requirement is to deliver 13.10 g of urea and 5.80 g of DAP per plant. If farmers desire to alter the fertilizer quantity for fulfil a different NPK ratio, they can do so by adjusting the exposure length of the fluted roller metering unit. A functional relationship among, stepper motor speed, fertilizer discharge rate, and the forward speed of the crop conveying unit was established by calibration (given in Eqs. (9) and (10) for urea and DAP, respectively).

Development of lab setup for the fertilizer applicator

Testing of the developed precise fertilizer applicator for cotton plants was conducted at the Farm Machinery Laboratory, Agricultural and Food Engineering Department, Indian Institute of Technology (IIT) Kharagpur (Fig. 9). The python-based cotton detection algorithm was uploaded to the computer via PyCharm® 2018.3.1 (JetBrains s.r.o, IntelliJ Software, Russia). Another arduino program was uploaded to the microcontroller (2KB SRAM, Smart Projects, Italy). The camera (Logitech Pro 9000) was connected to the computer via a USB cable. To account for the time gap between image acquisition and real-time fertilizer delivery, the camera was positioned 0.21 m in front of the fertilizer discharge tube. Vertical separation between the camera and the plant leaves was 0.16 m and the longitudinal length of canopy was measured using ImageJ software (LOCI, University of Wisconsin, USA). Illumination of the ambience ranged from 423 to 679 lx, measured with a digital lux meter (Metravi 1334, Metravi Instruments Pvt. Ltd., India). The crop conveying unit was driven by the motor through belt and pulley transmission, carrying cotton plants along the longitudinal direction of the lead screw. When a plant arrives in front of the webcam, the algorithm detects it. The processed single is sent to the microcontroller through serial communication between the developed algorithm and the microcontroller. The microcontroller drives the motor according to the received signal in the serial. The motor regulates the shaft of the fertilizer metering unit based on the machine's forward speed measured through a hall-effect sensor. The rotation

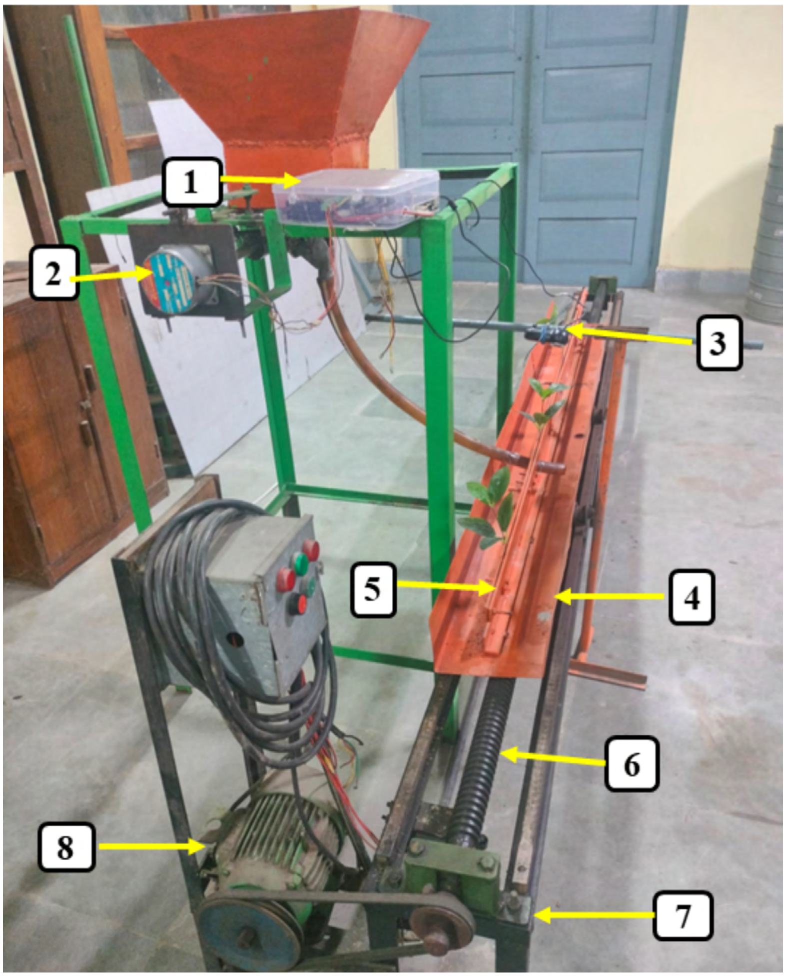


Figure 9. Laboratory setup for cotton fertilizer applicator: (1) developed embedded system; (2) stepper motor; (3) web camera; (4) crop holding platform; (5) crop holding unit; (6) lead screw; (7) frame; (8) AC motor.

of metering unit ensures the deliver the precisely-metered fertilizer near the plant (Fig. 10). The quantity of fertilizer depends on the setting of the exposure length of the fluted roller and the forward speed of the machine. The forward speed of crop conveying unit and fertilizer amount are crucial factors associated with the performance of developed cotton fertilizer. Tests were carried out for urea and DAP at five different constant forward speeds (0.2, 0.4, 0.6, 0.8, and 1 km/h) at a constant fertilizer amount per plant.

The relationship between the recommended application amount and the application amount was investigated for each fertilizer. The delivered application amount by MVES was compared with the recommended application amount using mean absolute percentage error (MAPE), which measures the system's accuracy by calculating the difference between the recommended and delivered application dose. Whereas, mean absolute deviation (MAD) indicated the average deviation. MAPE and MAD values were calculated using the following equations:

$$\text{MAPE} = \frac{1}{n}\sum_{i=1}^{n}\frac{|e_i|}{T_i} \quad (11)$$

$$\text{MAD} = \frac{1}{n}\sum_{i=1}^{n}|e_i| \quad (12)$$

where e_i is the difference between delivered and recommended fertilizer amount, and T_i is the delivered fertilizer amount.

Figure 10. Laboratory testing of the developed cotton fertilizer applicator.

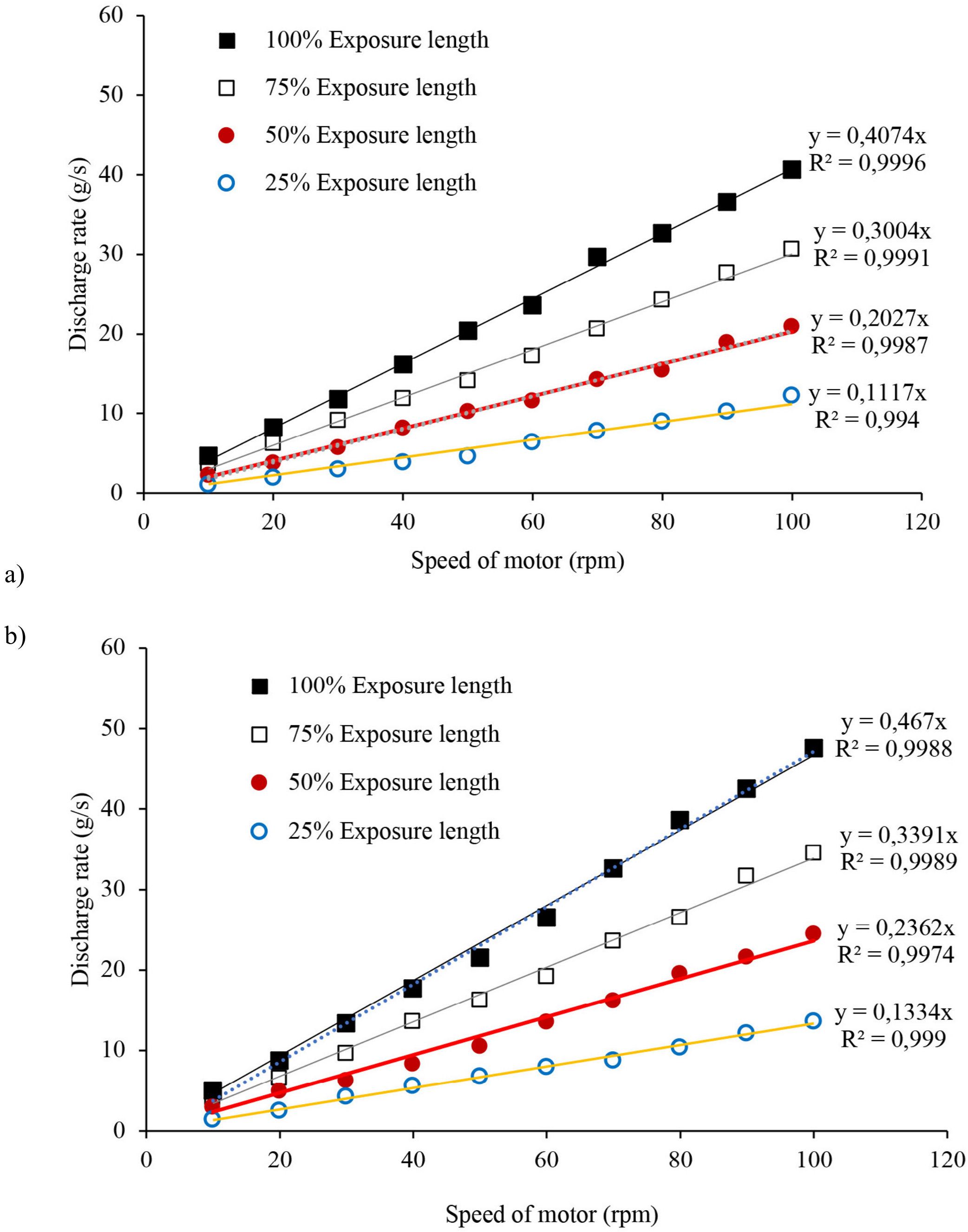


Figure 11. Discharge rate variation with motor speed for micro-granular cotton fertilizers: a) urea, b) DAP.

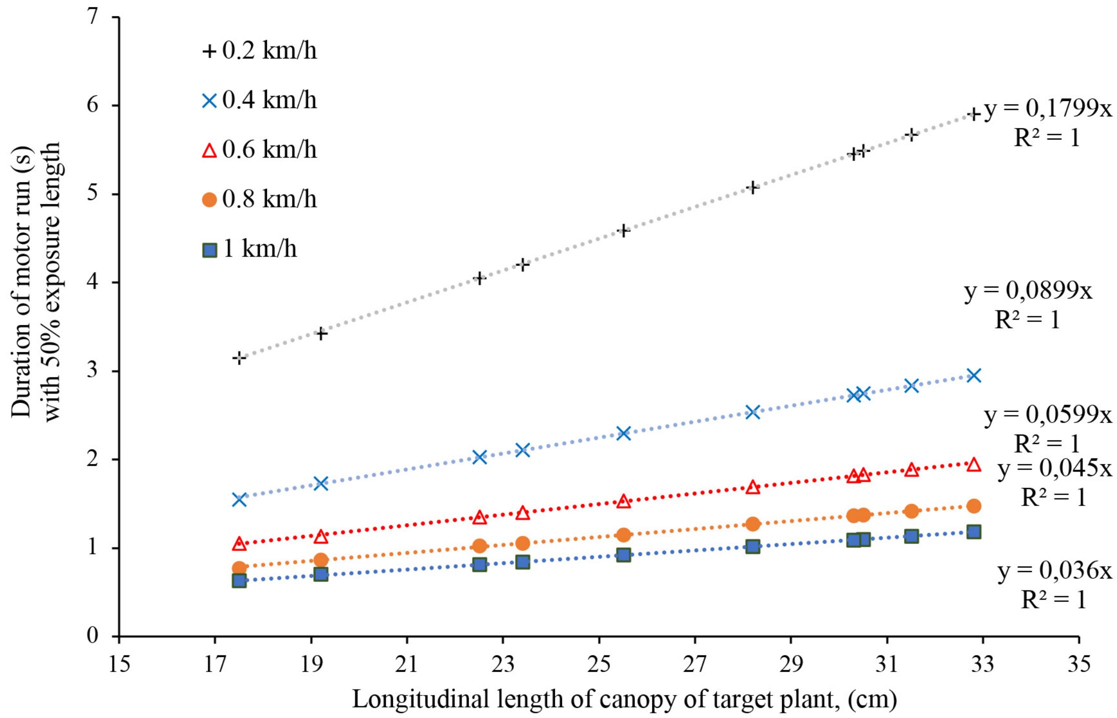


Figure 12. Duration of motor run for each plant with different longitudinal length of canopy. Regression equations and the coefficient of determination are shown corresponding to each forward speed.

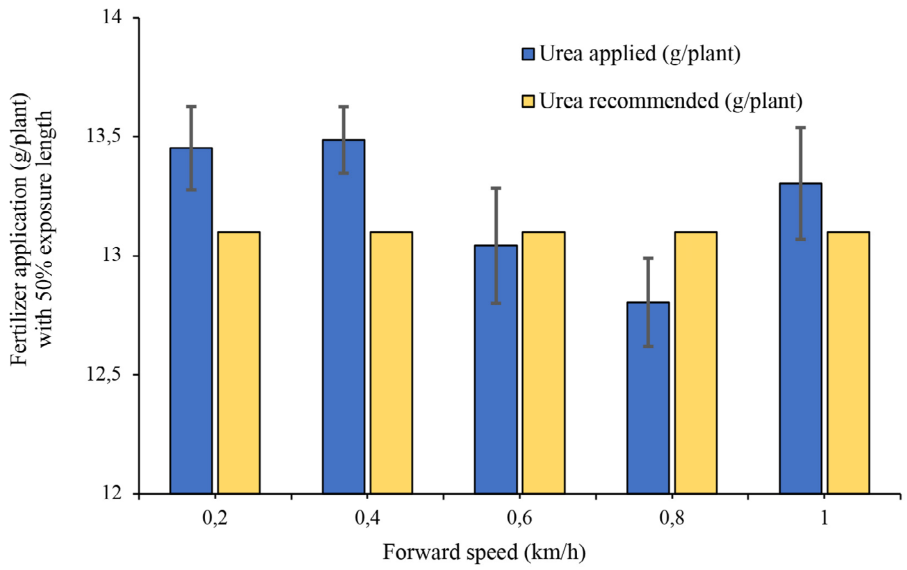
Results and discussion

Discharge rates were measured while running the fertilizer metering unit at various exposure lengths of the straight fluted shaft with eight flutes. The stepper motor changed the rotational speed from 10 to 100 rpm with intervals of 10 rpm. A physical balance (least count 0.01 g) was used to measure the fertilizer discharge amount. Subsequently, the exposure length was reduced to 75%, 50% and 25% of the total length and the discharge rates were measured (Fig. 11). For urea and DAP, the minimum and maximum discharge rates were, respectively, 1.03 g/s (at 10 rpm with 25% exposure length) and 40.47 g/s (at 100 rpm with 100% exposure length), and 1.43 g/s (at 10 rpm with 25% exposure length) and 47.20 g/s (at 100 rpm with 100% exposure length).

Duration of the stepper motor run depends on the received signal from the developed MVES. The duration of received signal (motor run continously) of detection depends on longitudinal length of the canopy of the cotton plant. For a larger longitudinal length of canopy, the stepper motor will run for a longer duration, and vice-versa. The fertilizer rate is thus varied depending on the duration of the motor run. The motor run duration was about 5.38 sec with fewer rpm (for slow forward speed) and about 0.62 sec with more rpm (for high forward speed). (Fig. 12). When all cotton seeds were sown at the same time, the longitudinal length of canopy was uniform among all plants. As a result, each plant obtained an equal fertilizer quantity. Nevertheless, in subsequent fertilizer applications, the longitudinal length of canopy extended. This results in an increased duration of the stepper motor's operation, causing a higher fertilizer distribution. To achieve even fertilization in the upcoming phase, fertilizer amount was reduced by decreasing the fluted roller metering unit's exposure length.

Variation between the delivered and recommended application amount for urea and DAP micro-granular fertilizers at fixed exposure length are shown in Fig. 13. The impact of variation of forward speed on the delivered amount of fertilizer was evaluated statistically. ANOVA revealed no statistically significant effect of forward speed on the discharge fertilizer amount ($p>0.05$ for both urea and DAP). Tola et al. (2008) and Alameen et al. (2019) found that the forward speed did not impact on the actual delivered amount of fertilizer ($p>0.05$). The MAPE was 5.71% & 8.5%; MAD, 0.74 g/plant & 1.12 g/plant for urea and DAP, respectively. May & Kocabiyik (2019) computed MAPE and MAD 8.9% and 1.03 g/plant, respectively. The developed MVES demonstrated high application accuracies, which varied between 88% and 90%, with an average of 89%. Kim et al. (2008) demonstrated that the precision of the developed granular applicator fell within the interval ranging from 81.9% to 97.4%, whereas system accuracy above 80% is considered acceptable. There was no statistically significant difference among MAPE and MAD value for both fertilizers ($p>0.05$ for both urea and DAP).

The variation of fertilizer application with different exposure lengths for urea and DAP micro-granular at a)



b)

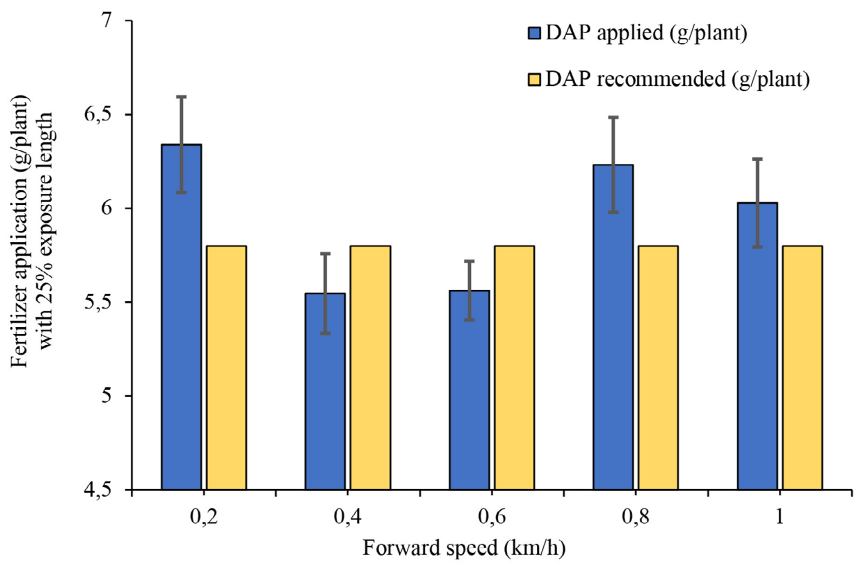


Figure 13. Comparison between delivered fertilizer dose and recommended fertilizer dose at different forward speeds for: a) urea, and b) DAP. Error bars show the standard error of mean

different forward speeds is shown in Fig. 14. Fertilizer application (g/plant) significantly increased with increase in the exposure length of fertilizer metering unit. However, the developed MVES could effectively offer fertilizer close to the recommended dose at all the forward speeds tested. The analysis showed no statistically significant difference in forward speed between delivered and recommended dose ($p>0.05$ for both urea and DAP), but statistically significant difference of exposure lengths on fertilizer application was noted.

The laboratory tests demonstrated that the machine vision-based algorithm could successfully identify cotton crops. However, the majority of existing fertilizer applicators are based on the broadcasting method, associated with excessive discharge rate, uneven dispersion of fertilizer, wasteful utilization of fertilizer, culminating in the proliferation of weed growth; placement-based fertilizer applicators require significant labor, consume a considerable amount of time and are applied in non-continuous manner. The developed fertilizer applicator mechanizes the

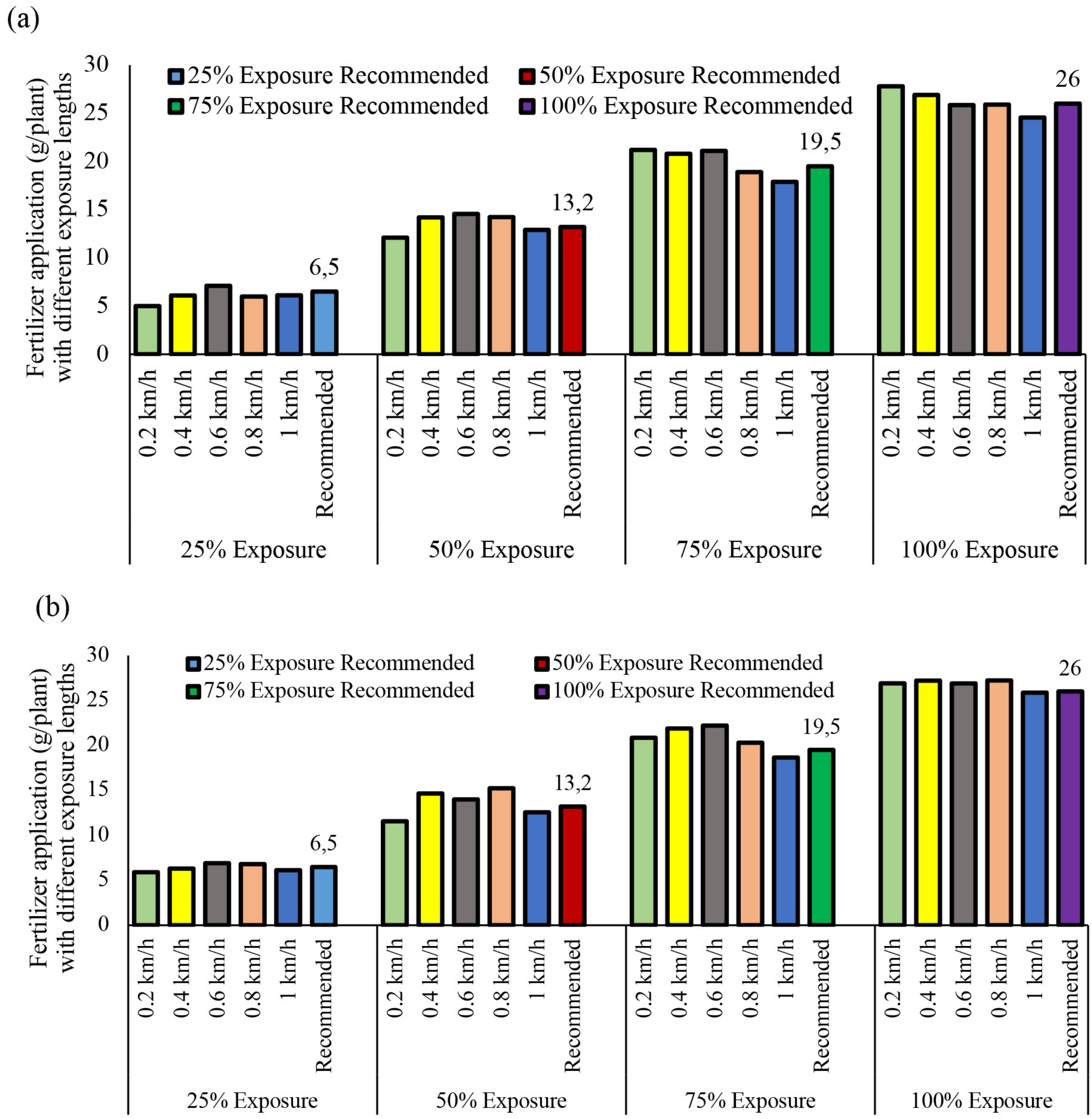


Figure 14. Variation of fertilizer application with different exposure lengths at different forward speeds for: a) urea, and b) DAP.

placement method and tackles the majority of problems associated with the existing applicators. In this study, the performance evaluation of the developed fertilizer applicator was focused on identify cotton crop, with precise and site-specific application. Future research is required to develop a deep learning-based model to avoid the presence of weeds, field testing and assaying other crops. However, the developed fertilizer applicator provides a potential solution to farmers to address the issue of input wastage, uniform distribution, site-specific application, and reduce the environmental effects.

In summary, the performance parameters indicated that the developed MVES system effectively and precisely applied the fertilizer amount with the recommended dosage. The system has the potential to mitigate metering inaccuracies arising from fluctuations in forward speed. The forward speed of the plant conveying unit showed no significant effect on the discharge quantity of fertilizer. The maximum deviation fertilizer between the applied amount and the recommended dose is lower than 10%, making the fertilizer application uniform across the field. The developed MVES has the ability to regulate the fertilizer metering unit at an accuracy of about 89%. The average time delay for dropping the fertilizer from hopper to plant was 380 ms. The developed machine vision-based cotton fertilizer applicator could offer economic as well as environmental benefits by precisely placing an appropriately-metered amount of fertilizer to each cotton plant individually. The developed fertilizer applicator using the machine vision technique upgrades the placement fertilizer method, enabling precise and site-specific application, reducing labor requirement, minimizing wastage, and reducing growth of weeds by site specific application.

Data availability: Data will be available on request.

Competing interests: The authors have declared that no competing interests exist.

Authors' contributions: Arjun Chouriya: Conceptualization, Data curation, Methodology, Formal analysis, Investigation, Software, Validation, Visualization, Writing-original draft. **Edathiparambil V. Thomas:** Conceptualization, Resources, Supervision. **Peeyush Soni:** Conceptualization, Formal analysis, Supervision, Project administration, Resources, Validation, Visualization, Writing-review and editing. **Vijay K. Patidar:** Data curation, Investigation, Methodology, Visualization. **Laxmi K. Dhruw:** Methodology, Software

Funding agencies/institutions: Agriculture and Food Engineering Dept, Indian Institute of Technology, Kharagpur, India.

References

Abdel-Aziz HMM, Hasaneen MNA, Omer AM, 2016. Nano chitosan-NPK fertilizer enhances the growth and productivity of wheat plants grown in sandy soil. Span J Agric Res 14(1): e0902. https://doi.org/10.5424/sjar/2016141-8205

Alameen AA, Al-Gaadi KA, Tola E, 2019. Development and performance evaluation of a control system for variable rate granular fertilizer application. Comput Electron Agr 160: 31-39. https://doi.org/10.1016/j.compag.2019.03.011

Bakhtiari MR, 2014. Selection of fertilization method and fertilizer application rate on corn yield. Agr Eng Int: CIGR J 16(2): 10-14. https://cigrjournal.org/index.php/Ejounral/article/view/2700.

Berenstein R, Edan Y, 2017. Human-robot collaborative site-specific sprayer. J Field Robotics 34(8): 1519-1530. https://doi.org/10.1002/rob.21730

Blumenthal JM, Baltensperger DD, Cassman KG, Mason SC, Pavlista AD, 2008. Importance and effect of nitrogen on crop quality and health. In: Nitrogen in the environment, pp. 51-70. Academic Press. https://doi.org/10.1016/B978-0-12-374347-3.00003-2

Chandel NS, Mehta CR, Tewari VK, Nare B, 2016. Digital map-based site-specific granular fertilizer application system. Curr Sci 111 (7): 1208-1213. https://doi.org/10.18520/cs/v111/i7/1208-1213

Evanylo G, Sherony C, Spargo J, Starner D, Brosius M, Haering K, 2008. Soil and water environmental effects of fertilizer-, manure-, and compost-based fertility practices in an organic vegetable cropping system. Agr Ecosyst Environ 127(1-2): 50-58. https://doi.org/10.1016/j.agee.2008.02.014

Fazhi P, Jianing H, Shuhong F, Zhijie Y, Zhen C, Zhiwen S, et al., 2022. Agricultural mechanical fertilizing device. Patent No. CN217644206U.

Ganesan P, Rajini V, 2014. Assessment of satellite image segmentation in RGB and HSV color space using image quality measures. Int IEEE Conf on advances in electrical engineering (ICAEE), pp. 1-5. https://doi.org/10.1109/ICAEE.2014.6838441

Gurjar B, Sahoo PK, Kumar A, 2017. Design and development of variable rate metering system for fertilizer application. J Agric Eng 54(3): 12-21.

Hou X, Fan J, Hu W, Zhang F, Yan F, Xiao C, et al., 2021. Optimal irrigation amount and nitrogen rate improved seed cotton yield while maintaining fiber quality of drip-fertigated cotton in northwest China. Indust Crops Prod 170: 113710. https://doi.org/10.1016/j.indcrop.2021.113710

Hu J, He J, Wang Y, Wu Y, Chen C, Ren Z, et al., 2020. Design and study on lightweight organic fertilizer distributor. Comput Electron Agr 169: 105149. https://doi.org/10.1016/j.compag.2019.105149

Hussein F, Janat M, Yakoub A, 2011. Simulating cotton yield response to deficit irrigation with the FAO AquaCrop model. Span J Agric Res 9(4): 1319-1330. https://doi.org/10.5424/sjar/20110904-358-10

ICAR, 2022. AICCIP annual report (2021-22). Central Institute For Cotton Research, Nagpur, India. https://aiccip.cicr.org.in/CD_21_22/aicrp-full-2022.pdf

Jamro SA, Shah AN, Ahmad MI, Jamro GM, Khan A, Siddique WA, et al., 2016. Growth and yield response of cotton varieties under different methods of fertilizer application. J Biodivers Environ Sci 9(4): 198-206.

Jotautiene E, Bivainis V, Mieldazys R, Gaudutis A, Jasinskas A, 2022. Experimental and numerical research of granular manure fertilizer application by centrifugal fertilizer spreading. Proc 21st Int Sci Conf "Engineering for Rural Development", Jelgava, Latvia, pp. 25-27. https://doi.org/10.22616/ERDev.2022.21.TF088

Kim YJ, Kim HJ, Ryu KH, Rhee JY, 2008. Fertiliser application performance of a variable-rate pneumatic granular applicator for rice production. Biosyst Eng 100(4): 498-510. https://doi.org/10.1016/j.biosystemseng.2008.05.007

Konduru S, Yamazaki F, Paggi M, 2013. A study of mechanization of cotton harvesting in India and its implications. J Agric Sci Technol B, 3(11B): 789.

Krishna, 2015. Fertilizer applicators and plant protection equipment, agricultural mechanization and automation. https://www.eolss.net/sample-chapters/c10/E5-11-02-03.pdf

Li L, Qian L, Yan-yan C, 2016. Half-precision self-walking variable fertilization seeder design. In J Hybrid Inform Technol 9: 177-188. https://doi.org/10.14257/ijhit.2016.9.9.17

Liu Q, Xu H, Yi H, 2021. Impact of fertilizer on crop yield and C: N: P stoichiometry in arid and semi-arid soil. Int J Environ Res Public Health 18(8): 4341. https://doi.org/10.3390/ijerph18084341

May S, Kocabiyik H, 2019. Design and development of an electronic drive and control system for micro-granular fertilizer metering unit. Comput Electron Agr 162: 921-930. https://doi.org/10.1016/j.compag.2019.05.048

Murray PJ, Cook R, Currie AF, Dawson LA, Gange AC, Grayston SJ, et al, 2006. Interactions between fertilizer addition, plants and the soil environment: Implications for soil faunal structure and diversity. Appl Soil Ecol 33(2): 199-207. https://doi.org/10.1016/j.apsoil.2005.11.004

Nkebiwe PM, Weinmann M, Bar-Tal A, Müller T, 2016. Fertilizer placement to improve crop nutrient acquisition and yield: A review and meta-analysis. Field Crops Res 196: 389-401. https://doi.org/10.1016/j.fcr.2016.07.018

Oberti R, Marchi M, Tirelli P, Calcante A, Iriti M, Tona E, et al., 2016. Selective spraying of grapevines for disease control using a modular agricultural robot. Biosyst Eng 146: 203-215. https://doi.org/10.1016/j.biosystemseng.2015.12.004

Pan S, Wen X, Wang Z, Ashraf U, Tian H, Duan M, et al, 2017. Benefits of mechanized deep placement of nitrogen fertilizer in direct-seeded rice in South China. Field Crops Res 203: 139-149. https://doi.org/10.1016/j.fcr.2016.12.011

Rahman KA, Zhang D, 2018. Effects of fertilizer broadcasting on the excessive use of inorganic fertilizers and environmental sustainability. Sustainability 10(3): 759. https://doi.org/10.3390/su10030759

Rakkar MK, Blanco-Canqui H, 2018. Grazing of crop residues: Impacts on soils and crop production. Agr Ecosyst Environ 258: 71-90. https://doi.org/10.1016/j.agee.2017.11.018

Ranjith M, Sridevi S, Ramana MV, Rao PC, 2015. Cotton productivity, profitability and changes in soil properties under different nutrient management practices. Int J Agr Environ Biotechnol 8(4): 915-922.

Reddy KN, Boykin JC, 2010. Weed control and yield comparisons of twin-and single-row glyphosate-resistant cotton production systems. Weed Technol 24(2): 95-101. https://doi.org/10.1614/WT-D-09-00044.1

Said KAM, Jambek AB, Sulaiman N, 2016. A study of image processing using morphological opening and closing processes. Int J Contr Theor Appl 9(31): 15-21.

Seenauth H, 2003. Granular fertilizer applicator, US Patent No. US6729558B1.

Shakoor A, Xu Y, Wang Q, Chen N, He F, Zuo H, et al., 2018. Effects of fertilizer application schemes and soil environmental factors on nitrous oxide emission fluxes in a rice-wheat cropping system, east China. PLoS ONE 13(8): e0202016. https://doi.org/10.1371/journal.pone.0202016

Sudkaew N, Tantrairatn S, 2021. Foliar fertilizer robot for raised bed greenhouse using NDVI image processing system. 25th IEEE Int Comput Sci Eng Conf (ICSEC), pp. 222-227. https://doi.org/10.1109/ICSEC53205.2021.9684580

Tackenberg M, Volkmar C, Dammer KH, 2016. Sensor-based variable-rate fungicide application in winter wheat. Pest Manage Sci 72(10): 1888-1896. https://doi.org/10.1002/ps.4225

Tewari VK, Pareek CM, Lal G, Dhruw LK, Singh N, 2020. Image processing based real-time variable-rate chemical spraying system for disease control in paddy crop. Artific Intellig Agr 4: 21-30. https://doi.org/10.1016/j.aiia.2020.01.002

Thorp KR, Ale S, Bange MP, Barnes EM, Hoogenboom G, Lascano RJ, et al., 2014. Development and application of process-based simulation models for cotton production: A review of past, present, and future directions. J Cotton Sci 18(1): 10-47. http://www.cotton.org/journal/2014-18/1/

Tola E, Kataoka T, Burce M, Okamoto H, Hata S, 2008. Granular fertiliser application rate control system with integrated output volume measurement. Biosyst Eng 101(4): 411-416. https://doi.org/10.1016/j.biosystemseng.2008.09.019

Tzionas P, Papadakis SE, Manolakis D, 2005. Plant leaves classification based on morphological features and a fuzzy surface selection technique. Fifth Int conf on technology and automation, Thessaloniki, Greece, pp. 365-370. https://doi.org/10.15388/Informatica.2005.104

USDA, 2021. Cotton: World Markets and Trade. United States Department of Agriculture Foreign Agricultural Service. https://www.fas.usda.gov/data/cotton-world-markets-and-trade.

Van Liedekerke P, Piron E, Vangeyte J, Villette S, Ramon H, Tijskens E, 2008. Recent results of experimentation and DEM modeling of centrifugal fertilizer spreading. Granular Matter 10: 247-255. https://doi.org/10.1007/s10035-008-0086-2

Wohab M, Gaihre YK, Ziauddin ATM, Hoque MA, 2017. Design, development and field evaluation of manual-operated applicators for deep placement of fertilizer in puddled rice fields. Agric Res 6(3): 259-266. https://doi.org/10.1007/s40003-017-0267-5

Xingsheng K, Liangqing S, Shaoren T, 2011. Precision cotton drilling fertilizer applicator. Patent No. CN202043435U.

Xiuyun X, Xufeng X, Zelong Z, Bin Z, Shuran S, Zhen L, et al, 2019. Variable rate liquid fertilizer applicator for deep-fertilization in precision farming based on zigbee technology. IFAC-PapersOnLine 52(30): 43-50. https://doi.org/10.1016/j.ifacol.2019.12.487

Yang G, Tang H, Tong J, Nie Y, Zhang X, 2012. Effect of fertilization frequency on cotton yield and biomass accumulation. Field Crops Res 125: 161-166. https://doi.org/10.1016/j.fcr.2011.08.008

Yildirim Y, 2006. Effect of vane number on distribution uniformity in single-disc rotary fertilizer spreaders. Appl Eng Agr 22(5): 659-663. https://doi.org/10.13031/2013.21998

Zhu ZL, Chen DL, 2002. Nitrogen fertilizer use in China-Contributions to food production, impacts on the environment and best management strategies. Nutr Cycl Agroecosyst 63(2): 117-127.

Zinkeviciene R, Jotautienė E, Jasinskas A, Kriaučiūnienė Z, Lekavičienė K, Naujokienė V, et al., 2022. Determination of properties of loose and granulated organic fertilizers and qualitative assessment of fertilizer spreading. Sustainability 14(7): 4355. https://doi.org/10.3390/su14074355