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Microcontroller based roller contact type herbicide applicator for weed control under row crops

V.K. Tewari [a,*], A. Ashok Kumar [b], Brajesh Nare [a], Satya Prakash [a], Ankur Tyagi [a]

[a] Agricultural and Food Engineering Department, IIT Kharagpur, India
[b] College of Agricultural Engineering, Madakasira, India

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ABSTRACT

A microcontroller based manually operated three row roller contact type herbicide applicator was designed and developed for control of the weed population in field crops. A control system was developed to apply the quantity of the herbicide based on quantified weed information. The unit consists of a camera for capturing the images of weeds, MATLAB software for image acquisition and processing in a laptop, a serial port communication for communicating between laptop and controller, a microcontroller for controlling the application of herbicide through a relay, and a dc solenoid valve for variable rate application of herbicide on the applicating roller. The captured image was analyzed by the image processing toolbox in the MATLAB software, to extract weed information in the image, which is then transferred to a microcontroller using serial port interface. The microcontroller activates the solenoid valve using a relay according to algorithm for decision of the herbicide amount. Field test results of the machine indicate an average of 50% saving in the amount of herbicide, with weeding efficiency of 90%.

1. Introduction

Weeds are plants, grown in unwanted areas, which impair the quality of farm produce and reduce the crop yields. Conventional farming system, apply high amount of herbicide. In order to reduce the herbicide application in agricultural fields, protect the environment and ensure water saving, precision application of herbicide is required. As herbicides became available, they gradually replaced cultivation as a method to control undesirable vegetation (Sprague, 1986). The conventional practice of applying herbicides uniformly across a whole field seems undesirable from both economic and environmental view points (Christensen et al., 1996). The most common type of herbicide application in India is direct spraying with the help of commercially available manual or power operated sprayers. However, the major problem in direct spraying is drift of chemical on non targeted areas. Contact transmission of the herbicide is an exact method of depositing the chemical at the target plants and is a possible solution to the above problem. Wyse and Habstritt (1977) developed a contact type herbicide applicator roller-wiper absorbing pad of carpet. Messersmith and Lym (1985) tested the roller-wiper technique for use in leafy spurge control. Cohen and Shaked (1982) developed a carpet recirculating glyphosate applicator for row crops using a carpet recirculatory applicator. Gaultney et al. (1984) evaluated the feasibility of roller wiper herbicide application for woody plant control. They used carpet covered roller mounted on front of a crawler tractor rotated at different speeds for study. Mayeux and Crane (1984) developed a carpet roller for range lands which was mounted on parallel linkage in front of a small farm tractor. Welker (1985) developed a surface-roller wiper to apply herbicides to broadleaf weeds in turf. They compared roller wiper and sprayer applications for drift hazards. No evidence of herbicide drift was found when 2, 4-D was applied with a roller wiper.

Tewari and Mittra (1982) developed and patented a manually pushed herbicide applicator (IITWAM-82) for row crops. He reported that the performance of sponge roller in Arhar crop was excellent and uniformity of application achieved was 100 per cent. The herbicide solution required was 100–120 l/ha. Welker (1985) developed a hand roller herbicide wiper for lawns and gardens. He reported that excellent control of broad leaf weeds was achieved using 2, 4-D, Paraquat and with no evidence of herbicide drift.

Researchers such as Brown et al. (1994) and Cho et al. (2002) had used CCD camera for image acquisition, but this type of camera is very costly. Therefore, this research concern to create an easily available web cam based image acquisition system. Leemans and Destain (2006), and Muangkasem et al. (2010) used digital camera

* Corresponding author.
E-mail address: prof.vktewari@gmail.com (V.K. Tewari).

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to capture an image and then further image processing was done on those captured images. The image processing is done on the basis of comparison of intensities of red (R), green (G) and blue (B) components of each pixel of an image. The green area of each image and the ratio of the green area to the whole image area (i.e. the greenness ratio) were determined, as an estimate of the weed coverage (Yang et al., 2003).

Most of the weeds are present in between inter row crop. Therefore, in this research only inter row weeds are considered. Several herbicide applications are done by researcher for inter row weeds. Paice et al. (1996) developed an experimental sprayer for investigating the effects of spatially variable herbicide dose. Their treatment was based on the treatment map prepared previously by weed mapping. Tian et al. (2000) developed and tested a machine-vision-system-guided precision sprayer. They integrated a real time machine vision sensing system with an automatic herbicide sprayer. However, the system was not sui for smaller weed patches.

This paper presents the development of a microcontroller based technology for site specific herbicide application with automatic weed detection technique, using machine vision and image processing for precise amount of herbicide application.

2. Methodology

2.1. General concept of herbicide applicator

The control system consists of digital cameras, laptop computer, Microcontroller, Relay, DC solenoid valve, and proximity switch. Camera captures ground cover underneath the camera and sends to laptop, where the application software process the captured image on the basis of comparison of intensities of R, G and B components of each pixel (the smallest single component of a digital image) of image. The image is analyzed at each pixel for weed detection. When G color intensity is greater than R as well as B color intensity the pixel is assumed to be green pixel, whereas, G color intensity is less than R as well as B color intensity that pixel is assumed to be background. The captured image having 640×480 pixels and the size of each pixel is 0.98 mm^2 at a height of 588 mm above the ground surface to capture the targeted area only in between crop row. The percentage of weeds present in between crop rows was calculated in terms of green index (Eq. (1)). Later on microcontroller activates the relay of each solenoid valve depending on the amount of herbicide required (Eq. (2)) on the application roller which rolls on the weeds smears chemical onto it. A proximity switch was installed with a ground wheel to sense the distance travelled by the rollers. As the rollers cover a distance of 600 mm, the proximity switch sends the signal to the camera through microcontroller to capture new image and the cycle will be repeated again. The Frame Grabe Interval property in MATLAB specifies how often the video input object acquires a frame from the video stream. The system acquires an image frame after every 600 mm distance and the extra frames acquired in that period are deleted. The weeds are killed in 48–72 h of time. The flow chart of the herbicide application control system is depicted in Fig. 1.

The weed density in between row crops is refers as Green Index (GI).

$$GI = \frac{\text{Total no. of green pixels in image frame}}{\text{Total no. of pixels in the same image frame}} \quad (1)$$

The green index is characterized into four levels i.e. (i) Very low (0–5%), (ii) Low (5–30%), (iii) Medium (30–70%) and (iv) High (70–100%).

The herbicide amount is calculated from following equation,

$$\text{Herbicide Amount} = R_A \times A \times \text{Green Index} \quad (2)$$

where R_A is the Rate of application of the herbicide per hectare and A is the Area covered by the image in ha.

2.2. Microcontroller processor design

A serial port (RS232) communication was used to transfer data (control signal for microcontroller) from laptop to microcontroller, Atmel AT89C2051. The signal was processed by the microcontroller for opening or closing the solenoid valve. Programming of microcontroller was done in assembly language. The 12 V DC normally closed solenoid valve was used and the circuit diagram is shown in Fig. 2.

2.3. Program for image acquisition and herbicide application

A Graphical User Interface (GUI) was developed with MATLAB software which allows the user to interact with electronic devices. Input parameters in GUI are application rate (AR), roller width (RW), operational speed (OS), and the output parameters are distance between camera and roller, camera height. Three push buttons OK, START, STOP are included in GUI. It also includes green index box as well as original and binary image box for each of camera mounted on machine. GUI programming in MATLAB has the following main parts, and a view of GUI is shown in Fig. 3.

a. Code block for calculation of distance between camera and roller, and height of camera.
b. Code block for configuring serial port properties and video input object properties.
c. Starting of video input.
d. Image acquisition, processing and green index calculation.
e. Algorithm for spraying decision.

During image processing, the red, green, and blue components of RGB image are extracted. Fundamental theory to discriminate weed from soil background was that the acquired image was separated into individual R, G and B components and for each pixel R, G and B values were compared, if green component intensity was greater than R as well as B component intensity, the pixel is identified as a green pixel i.e. a part of weed. When the green pixels are identified the original image is converted to binary image

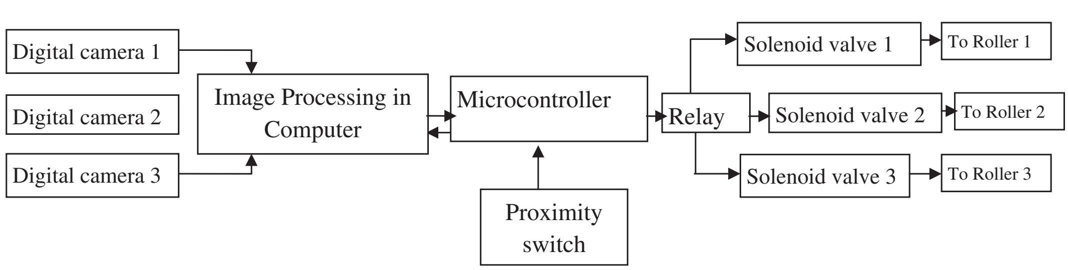


Fig. 1. Flow chart for herbicide application system.

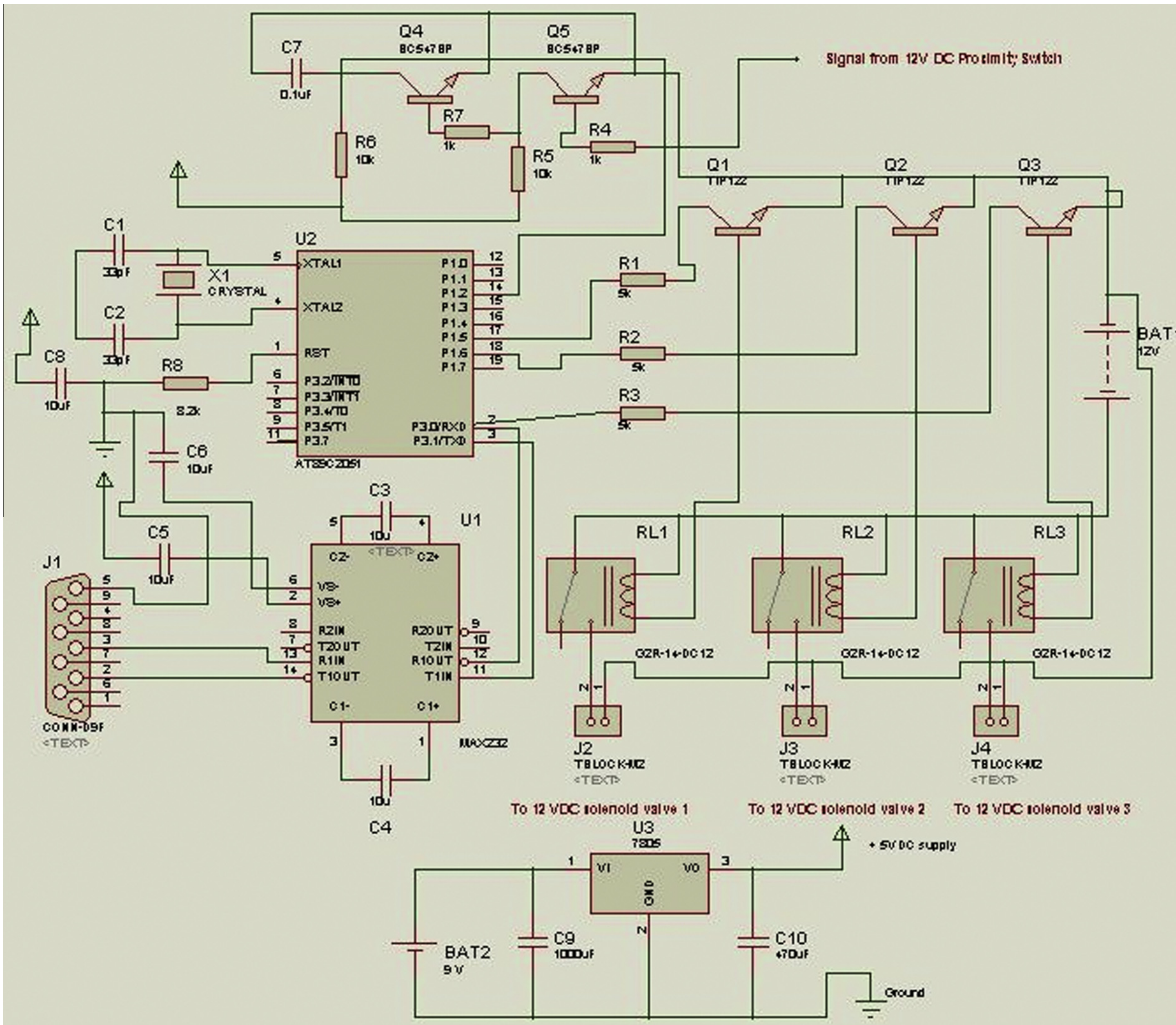


Fig. 2. Circuit diagram of processor along with pin configuration.

where weed pixels are represented by value 0 (black color) and soil background pixels are represented by value 1 (white color) as shown in Fig. 4. Code block calculates green index of given image and eventually displays original image with its binary image. After calculating green index, a decision either to apply or not to apply liquid is taken by algorithm for decision on the amount of herbicide application.

The algorithm provides herbicide application decision on the fact that if GI is in between 0.0 and 0.05, the weed quantity in given image area is very less and if herbicide was not applied for previous three image areas, then herbicide would be applied for the area from present image. In case of GI is in between 0.05 and 0.30, if herbicide was not applied for previous two image areas, then herbicide would be applied for the area from present image. In case of GI is in between 0.30 and 0.70, if herbicide was not applied for previous image area, then herbicide would be applied for the area from present image. In case of GI is in between 0.70 and 1.00 for every decision of herbicide is applied regardless of previous decision because this range of green index indicates area which is highly infested with weeds and needed full herbicide dose (Sharma, 2009). The algorithm decision of herbicide application is shown in Table 1. The designed and developed manually operated three row contact type herbicide applicator is shown in Fig. 5.

3. Laboratory and field tests

3.1. Laboratory test

The developed variable rate herbicide applicator was calibrated under laboratory condition by using carpets on the ground surface, having different green index levels and corresponding discharge of each solenoid valve was measured. The delay period for opening and closing of solenoid valve has been programmed in microcontroller according to the green index level based on laboratory calibration results for its variable discharge rate. It was observed, a variable amount of herbicide discharge from the solenoid valve according to different green index levels. The time duration for which solenoid valve remains open was calculated experimentally by using Eq. (3). The discharge of herbicide amount with respect to different green index levels from the solenoid valve under laboratory was compered with the actual herbicide amount discharge and is shown in Fig. 7. The laboratory results were recommended that, the developed unit was able to apply different amount of herbicide corresponding to the weed density.

$$\text{Time} = \frac{\text{Herbicide Amount}}{\text{Flow rate of liquid through solenoid valve}} \quad (3)$$

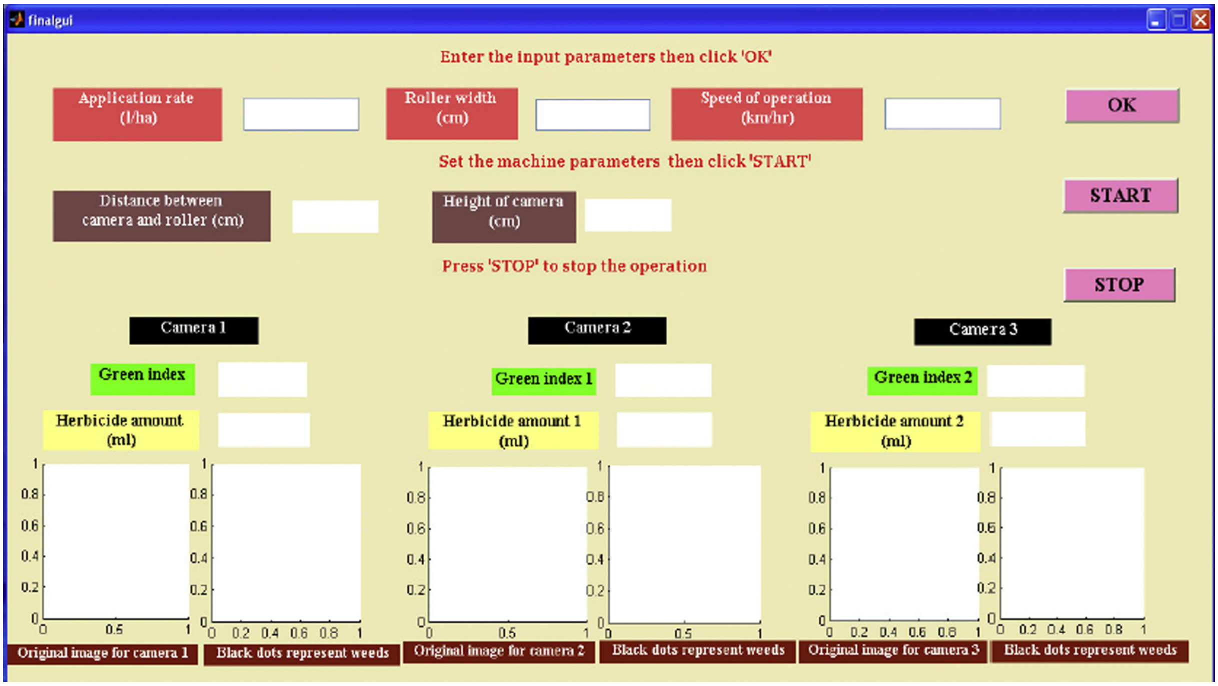


Fig. 3. Graphical user interface for image processing.

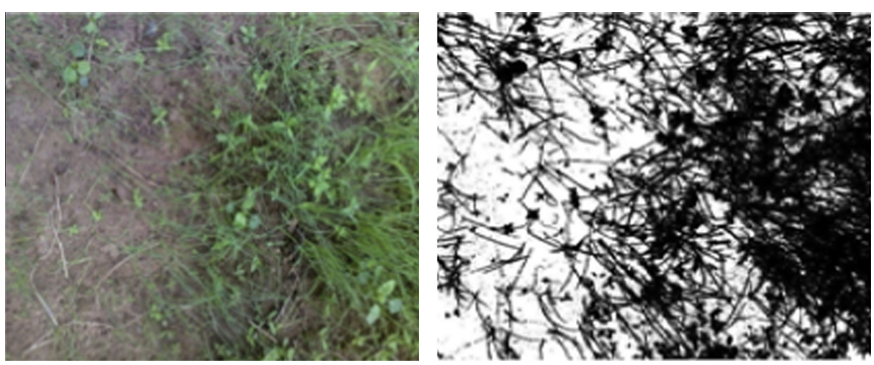


Fig. 4. Discrimination of weeds from soil background.

Table 1
The algorithm decision for herbicide application.

GI range	Q1	Q2	Q3	Q4
0.00 < GI ⩽ 0.05	N	N	N	Y
0.05 < GI ⩽ 0.30	Y	N	N	Y
0.30 < GI ⩽ 0.70	Y	Y	N	Y
0.70 < GI ⩽ 1.00	Y	Y	Y	Y

Where *GI* = Green index of image. *Q*1 = herbicide application decision in the previous 3rd image analysis. *Q*2 = herbicide application decision in the previous 2rd image analysis. *Q*3 = herbicide application decision in the last image analysis. *Q*4 = herbicide application decision in the current image analysis. *Y* is the representation of herbicide application. *N* is the representation of no herbicide application.

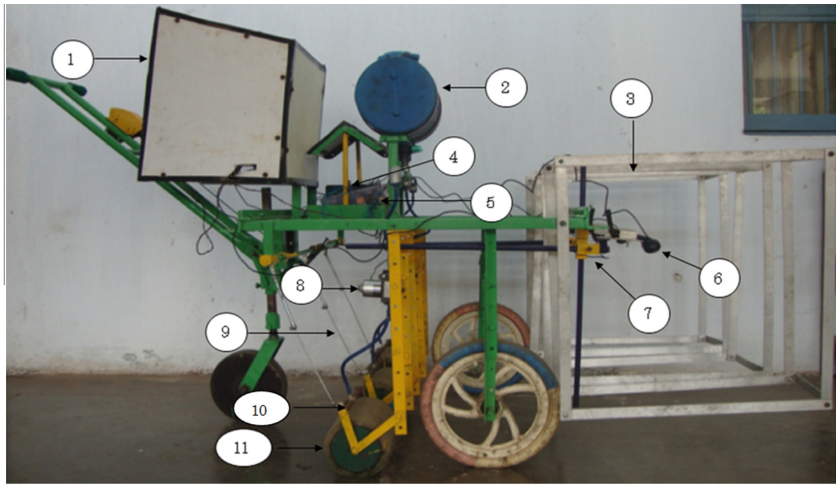
3.2. Field tests

Field tests of the developed herbicide applicator were carried out with respect to percent reduction in herbicide use, field efficiency and weeding efficiency. Maize and groundnut seeds were sown in a field of area 330 m^2 and 375 m^2 respectively with a row to row spacing of 30 cm as shown in Fig. 6 at research farm of IIT Kharagpur. Both the fields were sub divided into five sections and proper care was taken to maintain uniformity throughout the field. The field tests were conducted after 21 days of sowing for five replications in both fields. Herbicide used during the study was 'Paraquate dichloride' (non selective, contact type). The herbicide solution was prepared with 1:10 ratio of mixing herbicide with water and all connections of control system were made. The digital camera (Logitech quick cam pro 9000) in each row of the machine was fixed at a height of 588 mm above the ground surface and the distance between roller and camera was 655 mm. The delay period between images capturing and herbicide application was 1970 milli-sec. Reflectors were provided for each row to isolate the targeted area for avoiding the reflection of crop (Fig. 6). The operating speed of the machine was 1.2 km/h. The field of view (FOV) of the camera was 20° during field operation.

The percent reduction in herbicide consumption for maize and ground nut crops were calculated by using Eq. (4) .

$$\text{Reduction in herbicide use, } \% = 1 - \left(\frac{L_v}{L_c}\right) \quad (4)$$

where L_c = Amount of herbicide consumed in constant rate application, l and L_v = Amount of herbicide consumed in variable rate application, l.



1. Laptop, 2. Herbicide solution tank, 3.Deflector, 4.Battery, 5. Control unit. 6. Web camera 7. Camera height adjusting arrangement, 8.Solenoid valve 9. Mechanical linkage for lifting rollers 10.Dispensing manifold 11. Herbicide applicating roller

Fig. 5. Designed and developed microcontroller based herbicide applicator.

Fig. 6. Performance evaluation of herbicide applicator in maize and groundnut field.

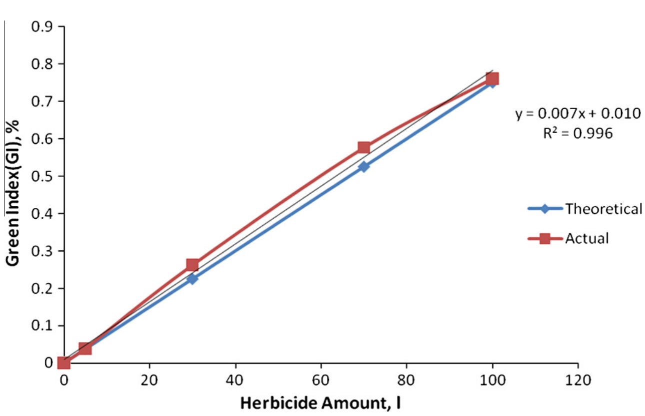


Fig. 7. Calibration curves of herbicide discharge and green index under laboratory conditions.

The weeding efficiency of the developed herbicide applicator was calculated by using Eq. (5) (Anonymous, 1985), for this a different field having an area 50 m^2 of groundnut crop and maize crop was prepared for determination of weeding efficiency (the ratio between the numbers of weeds killed by the herbicide applicator to the number of weeds present in a unit area and is expressed as percentage). In these fields three plots of 1 m^2 area were targeted for each green index varying from very low to high level.

$$W_f = \left(\frac{W_1 - W_2}{W_1}\right) \times 100 \quad (5)$$

where W_f = Weeding efficiency, %; W_1 = Number of weeds between two rows before weeding; W_2 = Number of weeds between two rows after weeding.

4. Results and discussion

Initially the unit was operated for constant rate application (without activation of cameras), during which, the consumption of herbicide solution was 297.61 l/ha recommended by Viswanath (2002), for maize and ground nut crop respectively. The unit was then operated for variable rate application by activation of cameras, during which, the consumption of herbicide solution was found to be 127.55–162.33 l/ha, 156.25–178.57 l/ha for maize and ground nut crop respectively for all five replications. The percent reduction in herbicide use for maize and ground nut crops were found to be 45.46–57.14 and 40–47.49 respectively and is given in Table 2 and 3. The herbicide consumption of groundnut crop was more than that of maize crop due to more weed density. The weeding efficiency was found to be an average of 90.16% and 89.60% ranging

Table 2
Herbicide application rate with variable rate system for maize crop field.

Sr. no.	Application rate (l/ha)		Reduction in herbicide use (%)	RD (%)
	Variable rate application	Constant rate application		
1	162.33	297.61	45.46	
2	160.25	297.61	46.15	
3	145.34	297.61	51.16	49.61
4	154.32	297.61	48.14	
5	127.55	297.61	57.14	

Table 3
Calculation of percent reduction in herbicide application for groundnut crop field.

Sr. no.	Application rate (l/ha)		Reduction in herbicide use (%)	RD (%)
	Variable rate application	Constant rate application		
1	178.57	297.61	40	
2	173.61	297.61	41.67	
3	166.67	297.61	44	43.30
4	168.91	297.61	43.24	
5	156.25	297.61	47.49	

from 88.45 to 93.27% with standard deviation (SD) 2.52 and 2.35 for ground nut and maize crop respectively. It showed that, the weeding efficiency was almost same for the selected plots of varying green index levels in both the crop field.

The variable rate herbicide applicator results were compared with constant rate herbicide applicator results using a statistical term, relative deviation (RD), which is defined as follows (Kumar and Pandey, 2012).

$$RD = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{H_c - H_v}{H_c}\right)100 \quad (6)$$

where, H_c is the Herbicide consumption by constant rate application, H_v is the Herbicide consumption by variable rate application, and N the number of observations. The RD values for the entire test observations were found less than 49.61% (Table 1). The analysis of the test results was done using the Duncan Multiple Range Test (DMRT) (Montgomery and Douglas, 2008). The analysis showed that the difference in constant rate herbicide application and variable rate herbicide application system was significant at 5% level.

5. Conclusions

By using the basic mechatronic a manually operated three row roller contact type herbicide applicator was designed and developed to optimize the herbicide application rate corresponding to the weed density under row crops to avoid the excess of herbicide consumption. A graphical user interface was successfully developed for displaying input and output parameter continuously in variable rate herbicide application mode for ease of operator interaction with the application system. This technology is simple and by using this, the wastage of herbicide can be avoided. It can be used for any dry land crop by making minor adjustments. From the field and laboratory results it can be concluded that, the applicator is able to apply variable amount of herbicide corresponding to the weed density.

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