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Development evaluation of tractor operated swinging lance sprayer for field crops

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Abstract
Application of pesticide in recommended dose not only reduces the input cost of chemical but also reduces the ill effects due to excess application of pesticide on crop and environment. A tractor operated swinging lance sprayer developed for effective application of chemicals. To standardize optimum operational parameters for developed sprayer, the effect of various factors at different levels need to investigate through experimentation. The optimum combination of operational parameters for effective spraying is spacing at 3.2m, spray gun height at 1.2m, swing angle 120^0 and operating pressure at 300PSI. The application rates of sprayer was 784L/ha, 604L/ha and 501L/ha at operating speeds of 0.75m/s, 1.0m/s and 1.25m/s respectively. CV in droplet size, droplet density, percent cover, volume of spray and relative span for top leafs was 4.14, 6.89, 5.56, 8.47 and 3.91 respectively, where as CV in droplet size, droplet density, percent cover, volume of spray and relative span for bottom leafs 6.89, 2.40, 5.99, 3.24 and 2.45 respectively. The theoretical field capacity of sprayer was 2.61ha/h, 3.48ha/h and 4.35ha/h at operating speeds of 0.75m/s, 1.0m/s and 1.25m/s respectively. Where as effective field capacity of sprayer were 2.0ha/h, 2.43ha/h and 2.66ha/h at operating speeds of 0.75m/s, 1.0m/s and 1.25m/s respectively. The bio-efficiency of sprayer to control pod bug in green gram filed was 68.6% and 88.45% at 3DAS and 5DAS respectively. The overall field efficiency of sprayer was 77%, 70% and 621% at operating speeds of 0.75m/s, 1.0m/s and 1.25m/s respectively.

Keywords: swinging lance sprayer, optimization, deposit scan, bio-efficiency

1. Introduction
Agriculture which accounts for about one-seventh of the GDP provides sustenance to nearly two-third of the Indian population. Food grain production increased from 52 million MT in 1951-52 to 295.67 million MT in 2019-20 (Anonymous, 2020). The important role played by plant protection practices is well recognized. Agriculture in developing countries suffers most because of the high incidence of various pests. Annual production loss due to pests estimated in India is US$ 42.66 million (Subash *et al.*, 2018). Application of pesticide in recommended dose not only reduces the input cost of chemical but also reduces the ill effects due to excess application of pesticide on crop and environment. Improvement of application techniques permits the effective use of chemicals and to reduce drift and harmful residues have become increasingly important.

In India, majority of farmers are using knapsack sprayer to apply plant protection chemicals and growth regulators. Knapsack sprayers are popular due to its low cost and ease of operation. The main drawback with knapsack spraying is of poor distribution pattern and labour intensive (Anibude *et al.*, 2016) [2]. In knapsack spraying technique more than 80% of chemicals are deposited on the ground, which is not desirable (Mishra *et al.*, 2015) [15]. Over dosage of pesticide leads to many problems, such as environmental pollution and chemical waste (Miranda *et al.*, 2017) [4].

Indian Tractor Industry contributing 35% of global volume with average annual growth rate of 10%. Farmers are using tractors as a versatile machine for various field operations. Even though tractor operated boom sprayer and self propelled boom sprayers with multiple nozzle are available commercially, small and marginal farmers are not attracting towards boom sprayer due to high purchase cost. Farmers are now showing interest towards tractor mounted sprayer fitted with two spray guns with hose length of 60 -300 m and operates with tractor PTH driven pump. To operate this type of sprayer requires four persons, of which two are for operating spray guns, one for driving tractor and another for adjusting hose pipe and filling chemical (Nageshkumar, 2017) [6].

This type of spraying technique purely depends on skill of the operator; there are chances of over dosage of pesticide, missing of pesticide. A tractor operated gun sprayer is not recommended technology due to its non-uniform spraying pattern. Hence, elimination of manual intervention with automatic operation of spray gun can improve the uniformity pattern.

To the author's knowledge, no significant work carried out on swinging lance spraying technique and no significant research findings reported. In the present study the design of various critical components, influence of various operational parameters and optimum combination of parameters for better performance of swinging lance sprayer, performance evaluation of developed sprayer carried out.

2. Materials and Methods

The present research work conducted at Division of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi during year 2020. Detailed procedure followed to conduct experimentation is discussed below.

2.1 Components and working of developed swinging lance sprayer

The developed swinging lance sprayer consists of MS frame for mounting of various components such as chemical tank, DC motors, pump, hose pipes, spray guns and three point hitch system. The mounting frame have provision to adjust spacing between spray guns (2m, 2.6m and 3.2 m), to adjust height of spray guns (0.9m, 1.2m and 1.4m) from the ground and to adjust swing angle (100º, 110º and 120º). The developed sprayer has three pressure adjustments (250PSI, 300PSI and 350PSI). Pump of sprayer runs with tractor PTO and V-belt drive used for power transmission. DC motors operates with tractor battery (12V), provision given to operate each spray gun separately, if required. A schematic diagram of developed sprayer is shown in Fig.1. It has a 400L capacity chemical tank with hydraulic agitation mechanism in order to maintain the homogeneity of liquid spray.

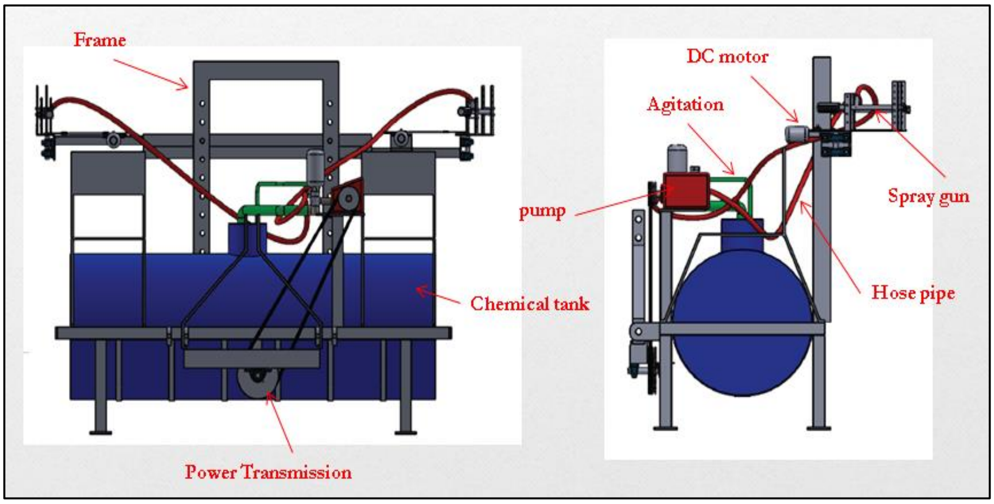

Fig 1: Schematic diagram of developed swinging lance sprayer

2.2 Optimization of operational parameters for developed swinging lance sprayer

To study the influence of various operational parameters and to identify optimum combination of operational parameters, a laboratory study was conducted. The experiment was conducted on concrete floor. Swinging lance spray attached to the tractor, tractor was at neutral position. Tap water used for conducting experiment. Initially, the left spray gun operated for 5 minutes whereas the right spray gun was in off condition. The wetted perimeter on a concrete floor for the left spray gun marked with orange color (Fig 2(a)). Later, the right spray gun operated for 5 minutes whereas the left spray gun was in off condition. The wetted perimeter on a concrete floor for the right spray gun marked with blue color (Fig 2 (b)). For each run, swath width, overlap, and length of spray measured (Fig 2 (c)). The same procedure followed for all the runs.

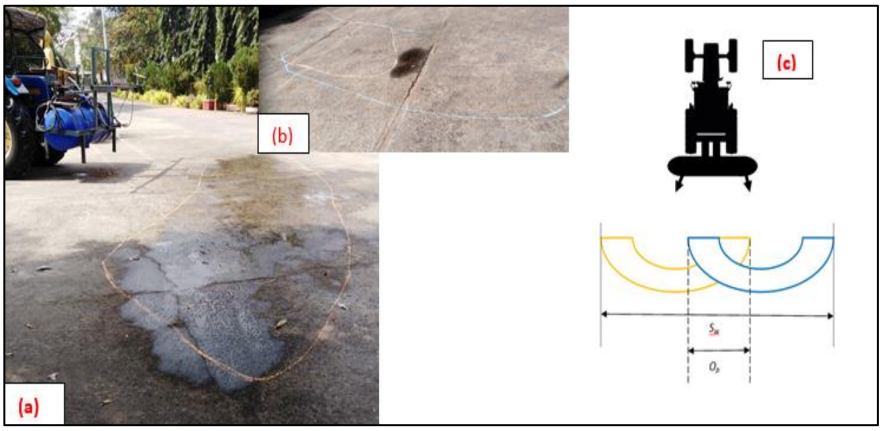

Fig 2: (a) marking of wetted perimeter for left spray gun (b) marked wetted perimeters for both the pray guns (c) a typical representation of swath width and overlap.

2.3 Performance evaluation of swinging lance sprayer

2.3.1 Discharge rate (L/min)

Discharge of gun sprayer was measured by volumetric method method. The spray volume was collected in a bucket for one minute duration for two spray guns at different operating pressures. Discharge from individual spray gun was collected separately at a time. During discharge collection, actuating mechanism was not operated. The quantity of water collected in bucket measured using measuring jar, measuring was performed in three replicates. Average of value of the discharge was considered as representative value. Fresh water used to measure the discharge rate of spray gun.

2.3.2 Application rate (L/ha)

To measure application rate of developed sprayer, a laboratory experiment was conducted in open field. A distance of 100m marked in open filed. Initially spray tank was completely filled with water; quantity of water sprayed to cover 100m distance was measured by suing top-up method. Application rate per hectare was calculated based on projection technique. The same experiment was conducted for three different speeds 0.75m/s, 1.0m/s and 1.25m/s and each experiment was repeated three times.

2.3.3 Droplet Analysis

Glossy photographic paper of size 5 × 2 cm was placed on upper side of the leaf at top as well as upper side of the leaf at bottom of the plant. They are fixed to leaves at location horizontally. Placement of glossy photo paper on plant is show in Fig.3(b). Methylene blue MS dye mixed @5 g/L in water sued as solution to analyze droplet deposition pattern. The dye solution sprayed on the crop by using developed sprayer. When the sprayed material dried, the glossy paper strips were collected for analysis in the laboratory with Deposit Scan software.

Fig 3: (a) Performance evaluation of sprayer in green gram field (b) Placement of glossy papers on crop

2.3.3.1 Deposit Scan

Deposit Scan is a scanning program that can quickly evaluate spray deposit distribution on water sensitive paper or kromokote paper *etc*. The DepositScan program offers a convenient solution for on-the-spot evaluation of spray quality even under field working conditions (Zhu *et al*., 2011) [9]. DepositScan specifically quantifies spray deposit distributions on any paper type collector that could show visual differences between spray deposits and the background. The shape of selected areas could be rectangular, elliptical or irregular. Any portable business card scanner with over 600 dpi can be used. When the Deposit Scan program was started, it opens an image-processing program, and prompts the user to scan the sample. The page heading of ImageJ program after Deposit Scan starts shown in Fig.4. The program then reports the individual droplet sizes, their distributions, the total number of droplets, and the percentage of area covered. Finally, the program batch file calculates $DV_{0.1}$, $DV_{0.5}$ and $DV_{0.9}$ and displays the results from the area of the selected section, the total number of spots and the percentage area covered by the spots.

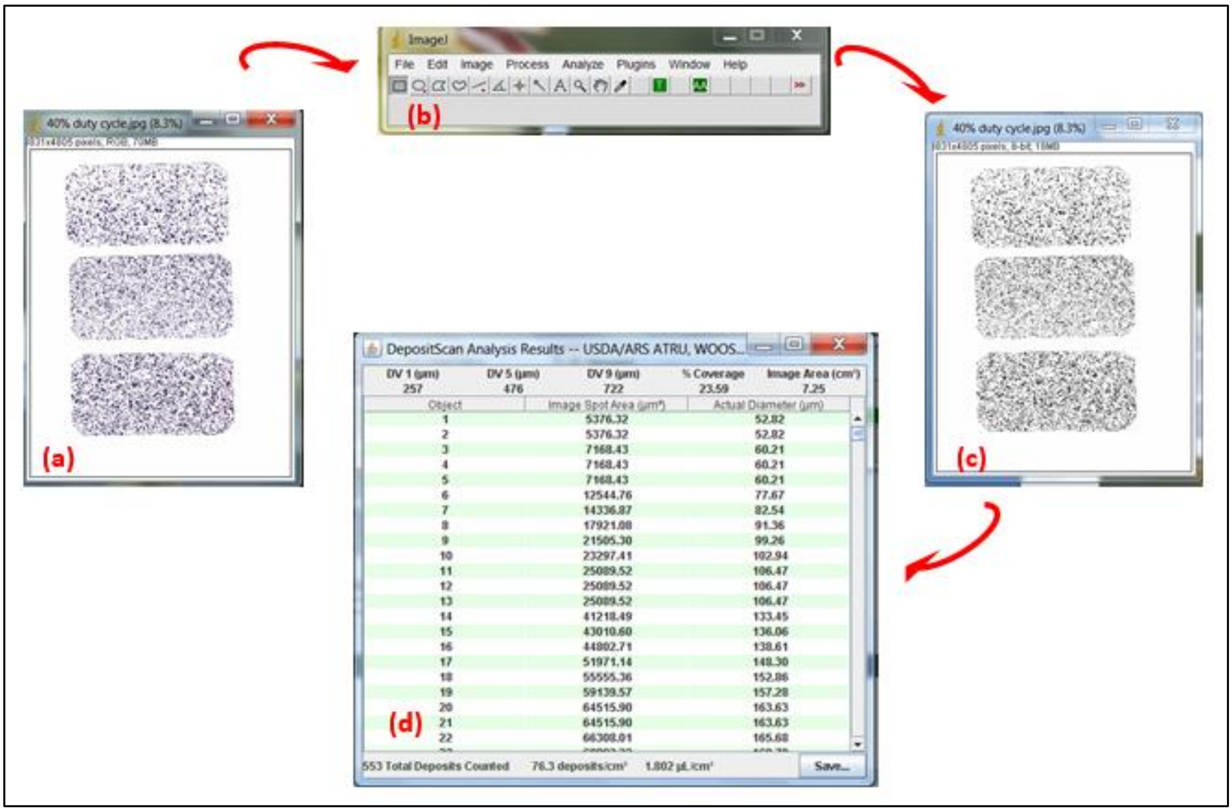

Fig 4: (a) Original scanned color image (b) DepositScan toolbar (c) converted 8-bit gray image (d) results window

2.3.3 Theoretical field capacity (ha/h)

Theoretical field capacity is calculated based on swath width of sprayer and speed of travel. Theoretical field capacity is always greater than effective field capacity. Theoretical field capacity was calculated based on following formula

$$\text{Theoretical field capacity, (ha/h)} = \frac{\text{Swath width(m)X speed(kmph)}}{10}$$

2.3.4 Effective field capacity (ha/h)

The effective field capacity is calculated based on the time consumed for real work and that time lost for other activities such as turning. The time required for actual work and time lost due to above factors measured by stopwatch. Effective field capacity was calculated using following formula

$$\text{Effective field capacity, (ha/h)} = \frac{\text{Actual area covered (ha)}}{\text{Total time required to cover area(h)}}$$

2.3.5 Field efficiency (%)

Field efficiency is the ratio of effective field capacity to theoretical field capacity. Field efficiency is always expressed in percentage.

$$\text{Field efficiency (\%)} = \frac{\text{Effective field capacity}(\frac{ha}{h})}{\text{Theoritical field capacity}(\frac{ha}{h})} \times 100$$

2.3.6 Bio-efficiency (%)

The field experiment conducted in green gram field after 60DAS to control pod bug (*Riptortus Pedestris*). Thiamethoxam 25% WG @100g/ha, spray liquid volume of 500L/ha sprayed on the crop. The following formula used to study bio-efficiency of spraying activity. Before spraying activity number of damaged pods counted from randomly selected plants. Number of damaged pods 3DAS and 5DAS also counted and compared with control.

Abbott's formula (Abbott, 1925)

$$\text{\% damage reduction} = 1 - \left(\frac{\text{n in T after treatment}}{\text{n in Co after treatment}}\right) \times 100$$

Where, n = no. of damaged pods; T = Treated; Co = Control

3. Results and Discussion

3.1 Optimization of operational parameters for developed swinging lance sprayer

The effect of operational parameters on swath width was shown in Fig.5. It is observed that swath width (S_w) increased with increase in spacing between spray guns and swing angle. It is also observed that swath width (S_w) decreases with increase in spray gun height. As the pressure increases swath width (S_w) also increased up to certain level, a further increase in pressure reduces swath width (S_w). From the optimization table, the predicted optimum operational parameters for obtaining maximum swath width for swinging lance sprayer was *s*=3.2m, *h*=1.2m, *a*=120^0 and *p*=300PSI.

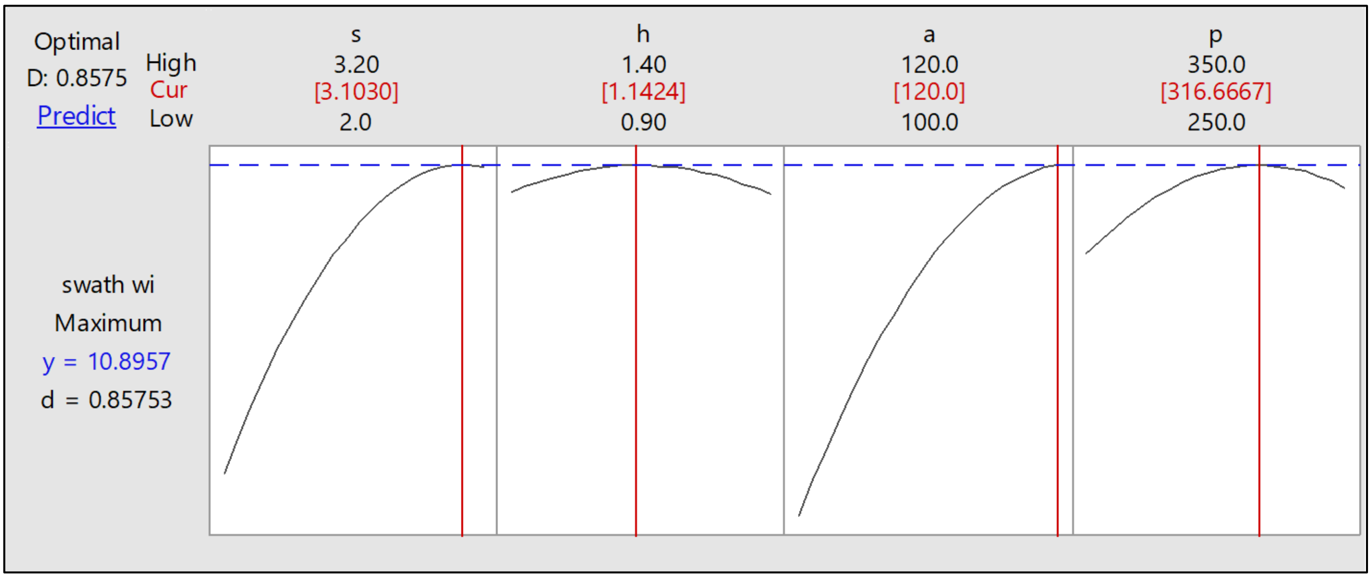

Fig 5: Optimization plot showing optimum operational parameters for effective swath width.

3.2 Performance evaluation of developed sprayer

3.2.1 Discharge

Discharge rate of spray gun is proportional to operating pressure. Discharge rate of Teejet spray gun varies 7.2 L/min – 11.4 L/min, when pressure varies from 100 PSI – 350 PSI. A graph showing trend of pressure Vs discharge rate is show in Fig.6.

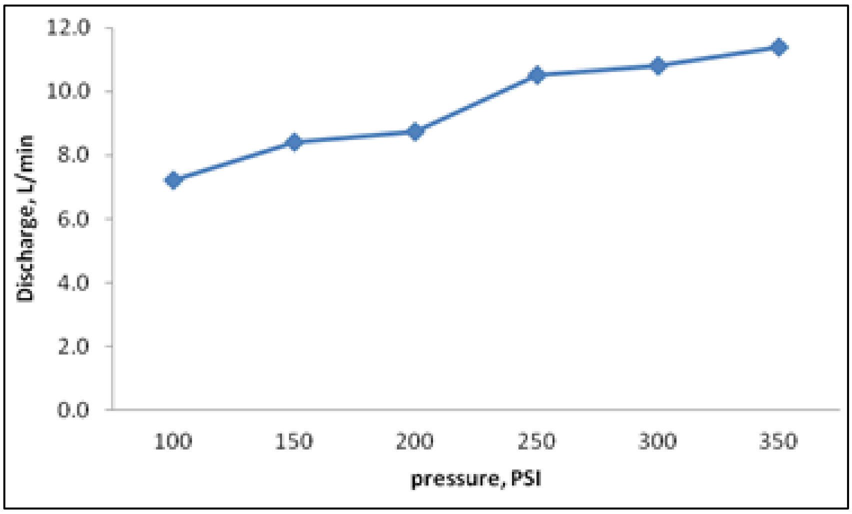

Fig 6: Graph showing pressure and discharge rate relation of spray gun

3.2.2. Application Rate

Application rate of developed sprayer decreases with increase in operational speed. The application rates of 784L/ha, 604L/ha and 501L/ha observed at operating speeds of 0.75m/s, 1.0m/s and 1.25m/s respectively. Graph showing speed and application relationship is given in Fig.7.

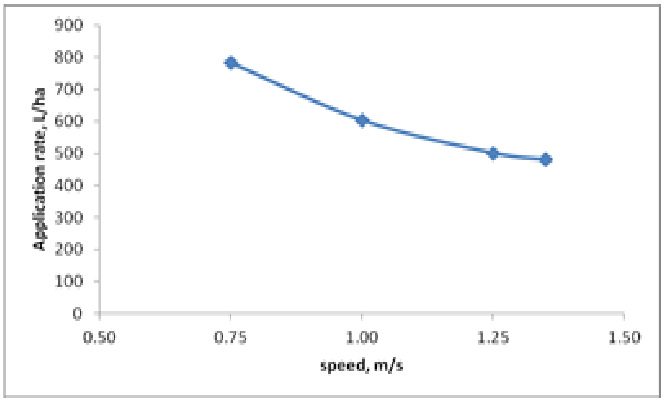

Fig 7: Graph showing relationship between speed and application rate of developed sprayer

2.4.3 Droplet Analysis

Spray droplets collected on glossy papers were analyzed with DepositScan software, the results of analysis presented in table 1 and table 2. Coefficient of variation in droplet size for top and bottom leafs was 4.14 and 6.89 respectively. CV in droplet densities for top and bottom leafs was 5.98 and 2.40 respectively. CV in percent cover, volume of spray, relative span for top leafs was 5.56, 8.47 and 3.91 respectively. Similarly CV in percent cover, volume of spray, relative span for top leafs was 5.99, 3.24 and 2.45 respectively. Hence from the results it is clear that the developed sprayer produced uniform spray pattern.

Table 1: Parameters analyzed by using DepositScan software for glossy papers placed on top leaf

Parameter	Top leaf	Mean	SD	CV
VMD (µm)	439-485	465	19.27	4.14
Droplet density (drops/cm^2)	104-127.8	116.16	6.95	5.98
% cover (%)	19-22	20.52	1.14	5.56
Volume of spray (µL/cm^2)	1.27-1.63	1.452	0.123	8.47
Relative Span	1.09-1.21	1.152	0.045	3.91

Table 2: Parameters analyzed by using DepositScan software for glossy papers placed on bottom leaf

Parameter	Bottom leaf	Mean	SD	CV
VMD (µm)	384-468	430	29.61	6.89
Droplet density (drops/cm^2)	68.9-73.4	70.96	1.7	2.40
% cover (%)	14-16.4	15.28	0.916	5.99
Volume of spray (µL/cm^2)	1.03-1.11	1.08	0.035	3.24
Relative Span	1.11-1.19	1.144	0.028	2.45

3.2.3 Theoretical field capacity

Theoretical filed capacity(ha/h) of developed sprayer increases with increase in operational speed. The theoretical field capacity of 2.24 ha/h, 2.98 ha/h and 3.73 ha/h observed at operating speeds of 0.75m/s, 1.0m/s and 1.25m/s respectively. Graph showing relationship between speed and theoretical field capacity is given in Fig.6.

3.2.4 Effective field capacity

The effective filed capacity (ha/h) of developed sprayer increases with increase in operational speed. The effective field capacity of 2.0 ha/h, 2.43 ha/h and 2.66 ha/h observed at operating speeds of 0.75m/s, 1.0m/s and 1.25m/s respectively. Graph showing relationship between speed and effective field capacity is given in Fig.8.

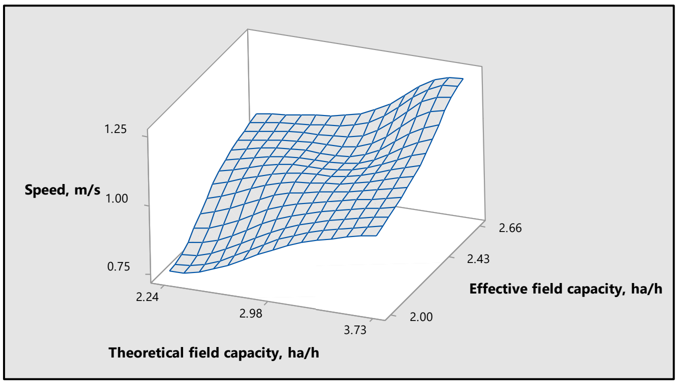

Fig 8: Surface plot showing relationship among speed, theoretical field capacity and effective field capacity developed sprayer

3.2.5 Field efficiency

The efficiency of developed sprayer decreases with increase in operational speed. The field efficiency of 89.5%, 81.5% and 71.4% observed at operating speeds of 0.75m/s, 1.0m/s and 1.25m/s respectively.

3.2.6 Bio-efficiency

The bio-efficiency of developed sprayer to control pod bug is studied at 3DAS and 5DAS. The percentage reduction in pod damage was 68.6% and 91.0% for 3DAS and 5DAS respectively.

4. Conclusions

Developed tractor operated swinging lance spryer performed in better way, controlled pod bug in green gram field effectively. The optimum combination of operational parameters for effective spraying is spacing at 3.2m, spray gun height at 1.2m, swing angle 120^0 and operating pressure at 300PSI. The application rates of sprayer was 784L/ha, 604L/ha and 501L/ha at operating speeds of 0.75m/s, 1.0m/s and 1.25m/s respectively. CV in droplet size, droplet density, percent cover, volume of spray and relative span for top leafs was 4.14, 6.89, 5.56, 8.47 and 3.91 respectively, where as CV in droplet size, droplet density, percent cover, volume of spray and relative span for bottom leafs 6.89, 2.40, 5.99, 3.24 and 2.45 respectively. The theoretical field capacity of sprayer was 2.24ha/h, 2.98ha/h and 3.73ha/h at operating speeds of 0.75m/s, 1.0m/s and 1.25m/s respectively, where as effective field capacity of sprayer was 2.0ha/h, 2.43ha/h and 2.66ha/h at operating speeds of 0.75m/s, 1.0m/s and 1.25m/s respectively. The bio-efficiency of sprayer to control pod bug was 68.6% and 91.0% at 3DAS and 5DAS respectively. The overall field efficiency of sprayer was 89.5%, 81.5% and 71.4% at operating speeds of 0.75m/s, 1.0m/s and 1.25m/s respectively.

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