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REDUCTION OF SPRAY LOSSES TO SOIL IN SOYBEAN (*GLYCINE MAX* L.) THROUGH OPTIMIZATION OF OPERATIONAL PARAMETERS

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Abstract: Spraying of plant protection chemicals is widely practised for minimizing the losses occurred due to attack of insect pests, and occurrence of diseases. However, indiscriminate and improper use of pesticide has brought up many environmental issues especially the soil pollution. Application of pesticide and its deposition at the target surface has drawn much attention to improve the efficacy of spray. A number of factors affect the deposition of pesticide on the plant surface and its loss to soil. These factors include both morphological characteristics of leaf and operational parameters of spraying. Among the operational parameters type of nozzle, pressure, droplet size, travel speed, etc. are some of the factors responsible for efficacy of spray on plant and losses to soil. Crop growth stage also affects the efficacy of the spray. The study established that spraying of insecticides with a suitable hydraulic sprayer fitted with HCN-80250 nozzle having provision for air supply at an advanced stage of crop growth with a travel speed of 3.5 km per hour ensure minimum spray losses to soil in soybean crop with considerably higher coverage area by the droplets on both sides of the leaves.

Key words: *spray loss, nozzle, spray coverage, crop growth stage, soybean*

INTRODUCTION

Soybean is one of the nine major oilseeds grown in India and it occupies first rank in terms of area under cultivation among oilseeds. During 2010-11, the total area under soybean was recorded as 9.60 million hectare with a production of 12.74 million tons

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[1]. The yield of soybean has however experienced high fluctuation during the last decade with an average yield of around 1006 $kg \cdot ha^{-1}$. About 58% of total area under soybean is in Madhya Pradesh and about 28% area belongs to Maharashtra. Therefore, unfavorable climatic conditions in these states coupled with infestation of pests and pathogens during *kharif* (rainy) season plays an adverse role in soybean production. Chemical control of insect pests and pathogens, which destroy up to one-third of the crop during different stages of crop growth, harvest and storage, is a very crucial field operation. It is generally agreed that the use of pesticides will increase, in spite of the exploitation of alternate methods of pest control. However, the rapidly increasing usage of pesticides, often with insufficient advice, has brought in its wake many environmental problems inimical to the interest of man [2]. Most of the sprayed pesticides usually reach to a destination other than the targeted zones causing an adverse effect on environment. The non-targeted areas like water-bodies, grasslands, residential areas and other habitats can be contaminated with pesticide residues as an outcome of run-off of the spray fluid from the foliage, drift of minute droplets of spray with air velocity, washing down of pesticides from plant to soil with rainwater, spilling of pesticide solution during filling of spray equipment and incorporation of remnants of plant parts treated with pesticide in the soil. The conventional technique for applying pesticides to agricultural crops is through dilution of pesticide with water. The spray solution can then be distributed evenly on the target crop by boom sprayers equipped with an atomizer system. The commonly used atomizer system is hydraulic nozzles where the spray liquid is atomized into droplets forming a spray with a pattern, which enables the even distribution of the spray on the intended targets. The boom and nozzles are placed typically at a height of 40 to 50 cm above the targeted zone. Pimentel stated that that less than 0.1% of pesticide applied for pest control reach their target pest in conventional spraying system [5]. However, some researchers reported absolute increase of deposit of the working fluid for 18% on the target surface with reduction of air flow angle relative to the direction of movement of aggregates, from 90° to 45° at a driving speed of 5 $km \cdot h^{-1}$ using air mist-blowers fan for dispersion of insecticide solution in vineyards [6]. The pesticide solution may also be dropped down through run-off from the leaves. Therefore, even in dense crops, a proportion of the spray liquid will be deposited on the soil below the crop [4].

After reaching to soil, the transport, persistence or degradation of pesticide depends on physical, chemical and biological properties of soil apart from the chemical composition of pesticide. Soil with high organic matter content improves sorption of pesticide molecules with soil particles, prevents the run-off and leaching of pesticides and thereby reduces the incidence of surface and ground water contamination. However, contamination of soil with pesticides result into suppression of population growth of beneficial soil microorganisms, reduction in population of certain soil invertebrates like nematodes and earthworms, predatory arthropods, pollinating insects, etc. It is also harmful for birds, wild and domesticated grazing animals and animals of aquatic ecosystems. It is also a persistent threat to human health and well-being.

A number of factors affect the deposition and retention of pesticide on the plants. The examples of such factors are canopy structure of the target crop, spray application factors and properties of the sprayed liquid and air-assistance to hydraulic boom of the sprayers. Leaf morphological features such as shape, leaf orientation and leaf age may also affect retention. A part of the spray can be lost during the application before the droplets are deposited on plants or soil. Droplets can be transported out of the sprayed field by spray drift. However, this loss is negligible under normal climatic conditions. Another loss comes from evaporation during the travel from nozzle to target. Apart from these factors, the travel speed of the sprayer also affects the retention of spray on the plant surface and the loss of spray chemical to the soil. Hislop highlighted the usefulness of air assistance on spraying at the rate of 0.72 $m^3 \cdot sec^{-1}$ and slower sprayer speed of 0.50 $m \cdot sec^{-1}$ as compared to conventional spraying without air-assistance at a forward speed of 2 $m \cdot sec^{-1}$ for obtaining higher spray deposit on the whole tillers by 66 to 71% and lower soil contamination by 46 to 66% depending upon size of droplets [3]. Therefore, determination of combination of different parameters like crop growth stages, selection of hydraulic nozzles, air assistance and forward speed is necessary for obtaining minimum spray losses to soil. Keeping these factors in view, an attempt was made to assess the quality of spray and the spray losses on soil for different types of nozzles with and without assistance of air at different forward speed and at various growth stages of soybean crop.

MATERIAL AND METHODS

The experiments were conducted using an over-head trolley set-up installed at plant protection laboratory of Central Institute of Agricultural Engineering, Bhopal in year 2012. Two hollow cone nozzles namely, HCN 80250 and HCN 80450 were selected for operating at recommended pressure of 3 $kg \cdot cm^{-2}$. The overhead trolley was fitted with a removable air sleeve attached to a centrifugal blower of 1 $m^3 \cdot s^{-1}$ air discharge capacity to supply the air into sleeves to examine the effect of air assistance on spray. The controller for the movement was programmed to have three levels of travel speed (1.5, 2.5 and 3.5 $km \cdot h^{-1}$) of the trolley for estimating spray deposition efficiency on crop and soil. Two rows of soybean plants were grown in two boxes mounted on a movable trolley filled with soil up to depth of 30 cm for conducting experiment inside the laboratory (Fig. 1) at two different growth stages of the crop viz. 45 days and 80 days after sowing (DAS). The system was mounted on the overhead trolley test setup such that a distance of 45 cm between nozzle and plant canopy is maintained.

Figure 1. Soybean plants grown on portable trolley

An aqueous solution of a red colored dye was used for spraying and the samples of droplet images were collected. The impression of droplets was collected on white paper tags (40 mm x 30 mm) with known spread factor mounted on both the front side and back side of the leaves as well as on soil surface between the rows. During spraying of the dye on one row of soybean plants, the other row was kept covered with polythene sheet to avoid unwanted exposure to spray solution (Fig. 2).

Figure 2. Spraying on one row of soybean plants keeping the other row covered.

After spraying on both the rows one by one, the paper tags were removed from the plants and allowed to dry to obtain the impression of droplets on paper tags (Fig. 3). The images of droplets were analyzed to estimate the coverage of spray using Leica QWin image analysing software after scanning the droplet images obtained on the paper tags. The droplet size of the spray discharge from both the nozzles and their distribution were measured by Spraytec Droplet Size Analyzer made by Malvern Instruments Ltd. U.K. Statistical analysis of the obtained data was done by using SAS 9.3 statistical software.

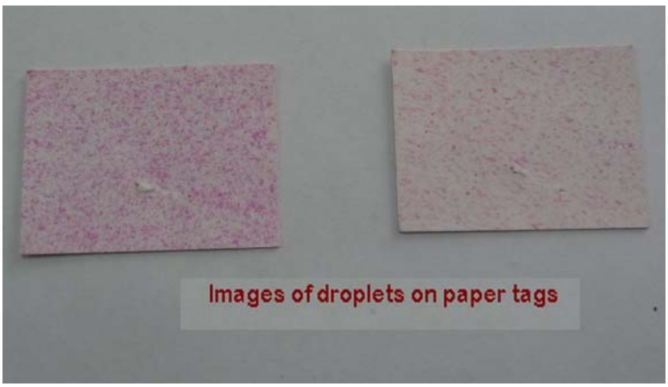

Figure 3. Impression of spray droplets on paper tags

RESULTS AND DISCUSSION

The droplet size and its distribution obtained from hollow cone nozzles at recommended pressure (3 kg·cm^{-2}) and varying forward speed of the overhead trolley were measured using droplet size analyser and the result is given below. In the case of HCN-80250 nozzle, the volume mean diameter (VMD) decreased with increase in forward speed of the system as a result of reduction in exposure time of larger droplets passing through laser beam of droplet size analyzer (Tab. 1). Though a reverse trend was observed while spraying with HCN-80450 nozzle having higher discharge rate where, fragmentation of larger droplets into smaller ones may not be materialized due to momentary period of contact at higher speed (Tab. 2) but this increase in droplet size was statistically insignificant. Most of the droplets were having a diameter of less than 200 micron which was well within the acceptable limit.

Table 1. Performance data of HCN 80250 for distribution of droplet sizes by volume

Forward speed (km·h^{-1})	*Droplet Size Distribution, (%)*					*Min. diameter (µ)*	*Max. diameter (µ)*	*Mean diameter (µ)*	*S.D.*	*C.V.*
	<100 (µ)	*100-200 (µ)*	*200-300 (µ)*	*300-400 (µ)*	*>400 (µ)*					
3.5	*0.05*	*77.25*	*18.98*	*0.03*	*5.46*	*166.74*	*195.33*	*178.88*	*3.49*	*1.95*
2.5	*Nil*	*75.49*	*22.94*	*0.26*	*1.84*	*169.28*	*201.74*	*183.25*	*2.69*	*1.47*
1.5	*Nil*	*46.83*	*49.49*	*1.23*	*3.69*	*188.62*	*234.02*	*203.10*	*4.48*	*2.21*
Tukey's HSD for mean droplet size = 4.60										

Table 2. Performance data of HCN 80450 for distribution of droplet sizes by volume

Forward speed (km·h^{-1})	*Droplet Size Distribution, (%)*					*Min. diameter (µ)*	*Max. diameter (µ)*	*Mean diameter (µ)*	*S.D.*	*C.V.*
	<100 (µ)	*100-200 (µ)*	*200-300 (µ)*	*300-400 (µ)*	*>400 (µ)*					
3.5	*0.17*	*53.72*	*44.08*	*1.43*	*1.18*	*178.32*	*231.91*	*197.03*	*9.54*	*4.84*
2.5	*0.03*	*55.14*	*44.01*	*0.14*	*0.92*	*174.46*	*230.01*	*193.73*	*10.6*	*5.48*
1.5	*0.12*	*75.42*	*23.67*	*0.46*	*1.13*	*161.97*	*208.16*	*181.55*	*12.7*	*7.01*
Tukey's HSD for mean droplet size = 17.57										

Effect of different crop growth stages on area covered by spray in soybean crop

The results obtained on percentage of area covered by droplets on leaves and soil for soybean crop at two different crop growth stages of 45 and 80 DAS revealed that the crop growth stage at 45 DAS displayed significantly higher coverage on front side of the leaves whereas, the effect of crop growth stage was insignificant on coverage of spray on back side of the leaves. However, the area covered by droplets on soil surface was significantly reduced at crop growth stage of 80 DAS Since, no specific conclusion can be drawn from absolute coverage of spray at different locations; it was decided to frame two ratios namely, the ratio of area covered by droplets on plant to area covered on soil and the ratio of area covered by droplets on backside of leaves to front side of leaves, keeping in view the aim of experiment towards reducing the spray loss on soil and increasing the deposit of spray on both sides of the leaves.

Further analysis based on these ratios indicated that crop growth stage exerted insignificant influence on the ratio of coverage on plants to soil but it exhibited significant impact on coverage on backside to front side of leaves (Tab. 3). The analysis also pointed out that at earlier stages of growth, spray discharge reached freely to almost all exposed sides of leaves and also drifted to soil due to the thinner canopy of the plants. At later growth stages, the dense canopy of the plants prevented the drift of spray to the ground. Therefore, it can be concluded that spraying at proliferated canopy ensures more uniformity of spray with reduction of spray being deposited on the ground.

Table 3. Effect of different crop growth stages on area covered by spray

Particulars	Percentage of area covered at		Difference	Tukey's HSD at 5% level
	45 D.A.S.	80 D.A.S.		
Front-side of leaves	14.63	9.78	4.85	1.79
Back-side of leaves	3.88	3.63	0.25	0.78
On soil surface	15.09	9.14	5.95	2.58
Ratio of coverage on plant to soil	1.46	1.58	0.12	0.30
Ratio of coverage on back-side to front-side of leaves	0.25	0.40	0.15	0.09

Effect of different hollow cone nozzles on area covered by spray in soybean crop

On the basis of area covered by droplets discharged from different nozzles, it was observed that HCN-80450 gave significantly higher coverage only on back side of the leaves whereas; HCN-80250 significantly reduced the area covered by droplets on soil. Further analysis indicated that HCN-80250 significantly increased the ratio of area covered on plants to soil while the nozzle HCN-80450 had an insignificantly higher ratio of area covered on backside to front side of leaves (Tab. 4). Therefore, it is advisable to select hollow cone nozzle HCN-80250 to decrease the spray losses to soil without compromising the penetration of spray in crop canopy.

Table 4. Effect of different hollow cone nozzles on area covered by spray

Particulars	Percentage of area covered from		Difference	Tukey's HSD at 5% level
	HCN-80250	HCN-80450		
Front-side of leaves	11.46	12.95	1.49	1.79
Back-side of leaves	3.17	4.35	1.18	0.78
On soil surface	9.19	15.04	5.85	2.58
Ratio of coverage on plant to soil	1.74	1.30	0.44	0.30
Ratio of coverage on back-side to front-side of leaves	0.28	0.36	0.08	0.09

Effect of air supply on area covered by spray in soybean crop

Providing air assistance during spraying of liquid significantly improved the deposition of spray on leaf surface as well as the penetration of spray into crop canopy but it also increased the deposition of sprayed droplets to soil. It was also observed that the ratio of area covered on plants to soil was significantly increased with provision of air supply but it had no significant effect on the ratio of area covered on backside to front side of leaves (Tab. 5).

Table 5. Effect of air supply on area covered by spray

Particulars	Percentage of area covered		Diffe-rence	Tukey's HSD at 5% level
	Without air supply	With air supply		
Front-side of leaves	9.14	15.28	6.14	1.79
Back-side of leaves	2.00	5.52	3.52	0.78
On soil surface	10.43	13.80	3.37	2.58
Ratio of coverage on plant to soil	1.17	1.87	0.70	0.30
Ratio of coverage on back-side to front-side of leaves	0.29	0.36	0.07	0.09

Effect of different travel speed on area covered by spray in soybean crop

Travel speed was found to be significantly affecting the area covered by droplets on soil and penetration of spray into the plant canopy. It was observed that reduction of forward speed to 1.5 $km \cdot h^{-1}$ significantly increased the coverage on both sides of the leaves. But it also increased the droplets reaching on soil due to enhanced exposure time. The results revealed that increasing the forward speed up to 3.5 $km \cdot h^{-1}$ significantly increased the ratio of coverage on plants to soil whereas, the ratio of coverage on backside to front side of leaves was maximum at a forward speed of 1.5 $km \cdot h^{-1}$ (Tab. 6). Again, a trade-off between these two objectives should be attempted looking at the deviation from optimized value of the parameters.

Table 6. Effect of different forward speeds on area covered by spray

Particulars	Percentage of area covered at			Tukey's HSD at 5% level
	1.5 $km \cdot h^{-1}$	2.5 $km \cdot h^{-1}$	3.5 $km \cdot h^{-1}$	
Front-side of leaves	13.64	12.41	10.57	2.65
Back-side of leaves	4.84	3.13	3.30	1.15
On soil surface	17.31	11.23	7.80	3.80
Ratio of coverage on plant to soil	1.20	1.46	1.90	0.45
Ratio of coverage on back-side to front-side of leaves	0.40	0.26	0.31	0.13

It is perceived that the selection of appropriate spraying parameters i.e. nozzle type, crop growth stage, provision for air blast and forward speed of the system can reduce the spray losses to soil and improve the penetration of spray droplets into the plant canopy as well. However, it is necessary to estimate the optimized value for these two ratios at appropriate levels of selected spraying parameters to reveal the precise potential of this technology in reduction of spray losses and improving the spraying efficiency. In this direction, two linear regression equations of crop growth stage, forward speed and provision for air blast on both the ratio of area covered on plant to soil and ratio of area covered on back-side to front-side of leaves were fitted to have two linear objective functions for maximization (Tab. 7). The provision for air support was included in the model as a dummy variable which was assigned the value as 1 when air assistance was provided and zero otherwise, considering only the observations with respect to already selected hollow cone nozzle HCN-80250.

Table 7. Aggregate linear effect of different spraying parameters on dependent variables

Dependent variable	*Estimates of parameters for*			*Coefficient of multiple determination (Adjusted R^2)*	*F value of the model*
	Crop growth stage	*Forward speed*	*Provision for air support*		
Ratio of coverage on plant to soil	*0.0062*	*0.3447*	*0.9453*	*0.9144*	*86.49****
Ratio of coverage on back-side to front-side of leaves	*0.0048*	*-0.0163*	*0.0375*	*0.7662*	*27.22****

**** - Significant at 1% level*

To maximize the developed equations under constrained condition to have an optimized value of dependent variables, linear programming technique following simplex algorithm was applied with three linear constraints as given below.

Maximizing:

$$Z_1 = 0.0062\, X_1 + 0.3447\, X_2 + 0.9453\, X_3 \tag{1}$$

$$Z_2 = 0.0048\, X_1 - 0.0163\, X_2 + 0.0375\, X_3 \tag{2}$$

Subjected to:

$$45 \leq X_1 \leq 80;\ 1.5 \leq X_2 \leq 3.5 \text{ and } X_3 = 1 \tag{3}$$

Where:

Z_1 [-] - ratio of coverage on plant to soil,
Z_2 [-] - ratio of coverage on back-side to front-side of leaves,
X_1 [D.A.S.] - age of crop,
X_2 [$km \cdot h^{-1}$] - forward speed,
X_3 [-] - dummy variable denoting air supply.

Table 8. Optimization of objective functions under constrained conditions

Objective	*Basic variables*	*Coefficient of basic variables*	*Optimal level of activity*	*Optimized value of objective function*
Maximization of ratio of coverage on plant to soil	*Crop growth stage*	*0.0062*	*80*	*2.6478*
	Forward speed	*0.3447*	*3.5*	
	Air supply	*0.9453*	*1*	
Maximization of ratio of coverage on back-side to front-side of leaves	*Crop growth stage*	*0.0048*	*80*	*0.3971*
	Forward speed	*-0.0163*	*1.5*	
	Air supply	*0.0375*	*1*	

The result obtained from the analysis illustrated that the maximum ratio of coverage on plant to soil was 2.6478:1 at a forward speed of 3.5 $km \cdot h^{-1}$ and the maximum ratio of coverage on back-side to front-side of leaves was 0.3971:1 at a forward speed of 1.5 km·h^{-1} with provision of air supply during spraying after 80 days from sowing (Tab. 8).

However, compromising the optimal solution by increasing the forward speed to 3.5 km·h^{-1} will reduce the value of second objective function to a sub-optimal level of 0.3645. Therefore, the system can be operated at a speed of 3.5 km·h^{-1} with provision of air supply to achieve the prime objective of reducing spray deposit on soil surface without losing the penetration capability of the spray droplets to reach on both sides of the leaves.

CONCLUSIONS

Therefore, the objective of minimizing the spray losses to soil in soybean crop can be achieved if spraying of insecticide is carried out using a suitable hydraulic sprayer fitted with HCN-80250 nozzle and blower of suitable size for air supply at a later stage of growth with a travel speed of 3.5 km per hour for ensuring higher field capacity without any significant reduction in coverage of the spray droplets on both sides of the leaves.

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SMANJENJE TROŠKOVA PRI PRSKANJU SOJE (*GLYCINE MAX* L.) OPTIMIZACIJOM RADNIH PARAMETARA

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Sažetak: Pskanje hemijskih sredstava za zaštitu bilja se široko primenjuje za smanjenje gubitaka koje uzrokuju insekti, štetočine i bolesti. Ipak, nepravilna upotreba pesticida ugrozila je životnu sredinu, posebno zagađenjem zemljišta. Primena pesticide i njihovo taloženje na ciljnoj površini privuklo je mnogo pažnje na unapređenje efikasnosti prskanja. Veliki broj faktora utiče na taloženje pesticide na površinu biljke i njihove gubitke u zemljištu. Ovi faktori uključuju, kako morfološke karakteristike lista, tako i radne parametre prskanja. Među radnim parametrima, na efikasnost prskanja i gubitke u zemljište utiču: tip mlaznice, pritisak, dimenzije kapljice, brzina kretanja itd. Stanje porasta useva takođe utiče na efikasnost prskanja. Ovim istraživanjem je utvrđeno da je prskanje insekticida odgovoarajućim hidrauličkim rasprskivačem sa mlaznicama HCN-80250, uz dodatno snabdevanje vazduhom, u naprednom stanju porasta useva i pri radnoj brzini od 3.5 $km \cdot h^{-1}$ obezbedilo minimalne gubitke kroz zemljište pri zaštiti soje. Uz to, postignuta je značajno veća površina pokrivena kapljicama, na obe strane lista.

Ključne reči: *gubici pri prskanju, mlaznica, pokrivenost sprejom, stanje porasta useva, soja*

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