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Fitting dose-response curve to identify herbicide efficacy and ED_{50} value in mixture

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ABSTRACT

Most of the farmers shifted to direct-seeded rice (DSR) from conventional puddled-transplanted system. One of the major challenges in DSR is weed management, which reduces the productivity of the rice system significantly. Therefore, many herbicide combinations are being tried for broad-spectrum control of weeds. In the present study, field experiments were conducted during *Kharif* 2013 and 2014 to know the herbicides efficacy when used in mixture using dose-response curve in DSR. The treatments comprised of tank-mix combinations of two herbicides *viz*. fenoxaprop (0, 30, 40, 50, 60 g/ha) and metsulfuron (0, 2.5, 3.0, 3.5, 4.0 g/ha) to control grassy and broad-leaved weeds, respectively in DSR. Among many non-linear dose-response models, hill model was found to be the best for the data. Results revealed that when fenoxaprop applied in mixture with metsulfuron, its efficacy increased/decreased 4-5% during both the years. Further, when metsulfuron was applied in mixture, its ED_{50} value was increased from 3.43 to3.62 g/ha as compared to its alone application. Thus, the study revealed the presence of antagonistic effect of fenoxaprop on metsulfuron when used in mixture, which ultimately resulted in reduced efficacy in terms of pre cent weed control.

Key words: Dose-response, Herbicide efficacy, Fenoxaprop, Hill model, Metsulfuron

In many Asian countries, rice was grown formerly in puddled-transplanted system. But nowadays, most of the farmers started to shift their rice cultivation to direct-seeded rice (DSR) from conventional puddled-transplanted rice (PTR) because puddling or repeated tillage under wet conditions need more labour, water, and energy (Mahajan *et al.* 2012; Chauhan *et al.* 2012). One of the major challenges in DSR is weed management, which reduces the productivity of the rice system significantly (Singh *et al.* 2007, Chauhan and Johnson 2010, Mahajan and Chauhan 2011). In this system, weeds germinate at the same time as rice seeds which in later stages give tough competition to the main crop. Yield losses due to weeds in DSR systems can go as high as 90% if no control measures are taken in time (Chauhan and Johnson 2011). Therefore, DSR system requires proper control of weeds to get the desired yield of the crop. Among all the methods of weed control, use of herbicides is established as a major method of weed control which led to development of many molecules for the control of broad-spectrum weeds.

Herbicides such as pendimethalin, oxadiazon, oxdiargyl, and pyrazosulfuron as pre-emergence; and bispyribac-sodium, azimsulfuron, penoxsulam, fenoxaprop, and 2,4-D as post-emergence have been reported to provide effective weed control in rice (Chauhan 2012). However, use of single herbicide is often not sufficient to control all weeds effectively in DSR systems. Further, the continuous use of a single herbicide over a long period of time may develop herbicide resistance against some weeds and shifts in weed flora (Buhler *et al.* 2000, Chauhan *et al.* 2012). Therefore, herbicide combinations are being tried for achieving broad-spectrum weed control.

Information regarding the optimum combination of two herbicide doses is of substantial significance in weed control. In the past, studies have been conducted where dose-response curves have been used to study the biological effects of herbicides for weed control, resistance of weeds, and herbicide persistence in soil (Streibig 1987, Streibig *et al.* 1993, Streibig and Jensen 2000, Price *et al.* 2012). Studies on dose-response relationship is important to know the herbicide efficacy and mode of action. In order to improve weed control efficacy and reduce the application costs, the use of herbicide mixtures has become popular in many countries (Kudsk 2002). This strategy also characterises an important means to avoid problems related to herbicide resistance

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(Friesen *et al*. 2000, Sattin *et al*. 2000), but it requires some preliminary information to assist farmers with the process of herbicide and dose selection. Keeping this in view, a field experiment was conducted to know the herbicides efficacy in mixture using dose-response curve in direct-seeded rice.

MATERIALS AND METHODS

A field experiment was conducted on direct-seeded rice (DSR) during *Kharif* 2013 and 2014 at the experimental farm of ICAR-Directorate of Weed Research, Jabalpur situated at 23.90° N latitude, 79.58° E longitude and at an altitude of 412 m above mean sea level. The climate of study area is characterized by mean annual precipitation of 1277 mm, mean annual temperature of 24.6°C, mean annual maximum temperature of 31.27°C and mean annual minimum temperature of 17.97°C.

The soil of the experimental field was clay loam, pH 6.9 and OC 0.71%, low in N, medium in available P and K. The field was prepared by giving two ploughings, one with cultivator and another with rotavator. Rice (cv. *Kranti*) was dry-seeded at 30 kg/ha with tractor mounted seed-cum-fertilizer drill. The crop was sown in rows 18.5 cm apart at a depth of 2-3 cm on mid-June and harvested in early-November. The field was surface-irrigated after seeding for uniform germination, and further, irrigation was given as per requirement of crop. Nitrogen was applied at 120 kg/ha in three splits, 1/3 each as basal, at 28 DAS (tillering) and at 60 DAS (panicle initiation). Phosphorus at 60 kg/ha as P_2O_5 was applied with the zero-till cum fertilizer drill machine during seeding. Potassium at 60 kg/ha as K_2O was broadcasted uniformly before rice seeding.

The experiment was laid out in 5^2 factorial randomized block design with 3 replications. The treatments comprised of tank-mix combinations of two herbicides *viz*. fenoxaprop and metsulfuron. Fenoxaprop was used to control grassy weeds at 0, 30, 40, 50, 60 (recommended) g/ha whilemetsulfuron was applied at 0, 2.5, 3.0, 3.5, 4.0 (recommended) g/ha to control broad-leaved weeds.

Data recording and treatment

Herbicides were tank-mixed in specified doses for making different combinations and applied to the crop at 25 DAS. Twelve days after the application of herbicides, data on per cent weed control were observed. Error assumptions (normality, randomness and homogeneity of the error variance) were confirmed with studentized residuals and Shapiro-Wilk normality test before fitting the model. Data were found non-normal, therefore arc sine transformation was applied to the data to make its distribution normal so that data meets the assumptions before analysis.

Model fitting

Non-linear models describing biologically realistic dose responses are preferred over essentially invalid models such as straight line, polynomials, and inverse polynomials. Dose-response curve are generally used to fit data on doses of herbicides and response of weeds in terms of weed control (Green 1991). The plot of curve can be easily interpreted and is immediately informative to readers. In the present study, non-linear dose-response models were fitted to the data *e.g.* logistic, log-logistic, log-probit, Hill function and variant of these models (with intercept and without intercept). These are all *S*-shaped curve and help in understanding the dose-response relationships. Among all, dose- response Hill model was found to be best for the data. Dose-Response Hill function is given by: $y = \delta + \frac{\alpha x^{\theta}}{\varphi^{\theta} + x^{\theta}}$ where, y is the % weed control, δ is intercept, $\alpha = y_{max}$, x denote the dose, θ is the hill coefficient of sigmoidicity and φ denote the ED_{50} value or the dose for which 50% weed control is obtained. Hill model is very flexible and effective in fitting experimental data (Goutelle *et al.* 2008).

RESULTS AND DISCUSSION

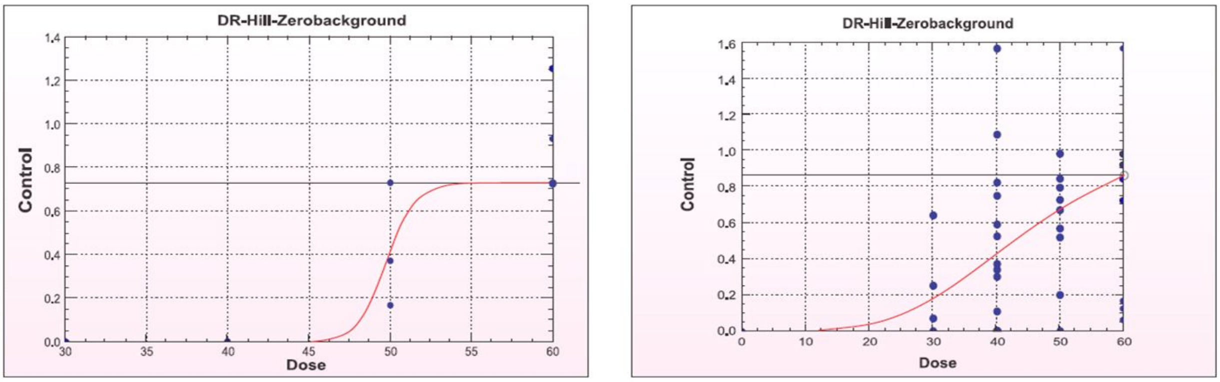
Weed flora

The field was mainly infested with *Echinochloa colona, Alternanthera sessilis, Eclipta alba, Ludwigia adscendenus, Dinebra retroflexa, Cyperus iria, Ammania baccifera* and *Commelina benghalensis* with varying density in two years. Total weed flora consisted of 73% broad-leaved species, 11% grassy and 16% sedges in 2013. In the year 2014, weed flora consisted of 46% broad-leaved, 22% grassy and 32% sedges.

Herbicde dose and plant response

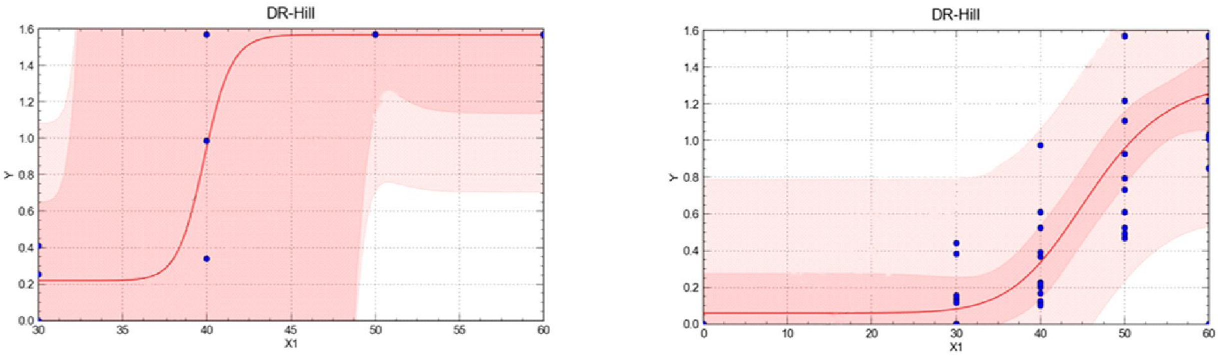
In our study, in 2013, fenoxaprop poorly controlled grassy weeds at recommended dose (60 g/ha) as well as at lower doses. However, in 2014, it controlled all grassy weeds even at lower doses. Different graphs were obtained by fitting the hill model to the data.

Figure 1(a) revealed that 68% of grassy weeds were controlled with full dose of fenoxaprop when applied alone. Its ED_{50} value was estimated as 49.7 g/ha from the fitted model. It is clear from **Figure 1(b)**



(a) $y = \frac{0.726x^{57.06}}{49.71^{57.06}+x^{57.06}}$ (b) $y = \frac{0.85x^{4.05}}{44.9^{4.05}+x^{4.05}}$

Figure 1. Dose response curve of weed control data (arc sine value) obtained from experimental plots where fenoxaprop alone (a) or in mixture (b) was used to control grassy weeds in DSR during *Kharif* 2013



(a) $y = 0.221 + \frac{1.54x^{49.4}}{39.8^{49.4}+x^{49.4}}$ (b) $y = 0.062 + \frac{1.28x^{9.58}}{45.7^{9.58}+x^{9.58}}$

Figure 2. Dose response curve of weed control data (arc sine value) obtained from experimental plots where fenoxaprop alone (a) or in mixture (b) was used to control grassy weeds in DSR during *Kharif* 2014

that when fenoxaprop was applied in combination with metsulfuron, its control efficacy increased from 68 to 73% and ED_{50} value reduced to 44.9 g/ha from 49.7 g/ha when applied alone.

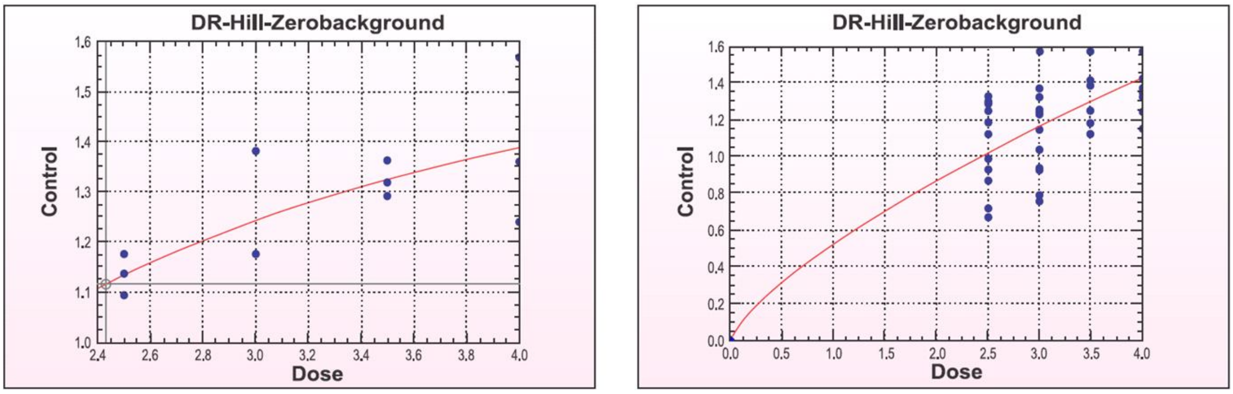
The relationship between herbicide-dose and plant-response (in terms of weed control) is of fundamental importance in understanding herbicide efficacy (Seefedlt 1995). The classical bioassay, often used to quantify the amount of herbicide in soil, employs a single 'standard' dose-response curve. This standard curve is then used to estimate the amount of herbicide in an unknown sample based on plant response in the sample (Nyffeler *et al.* 1982). The optimal herbicide dose is influenced by how much to be applied to avail an acceptable level of control. Therefore, in order to optimize herbicide usage, a knowledge of efficacy is necessary (Pannell 1990).

Analysis also revealed that almost 100% control of grassy weeds was achieved with recommended dose (60 g/ha) of fenoxaprop when applied alone during 2014 (**Figure 2a**). It has been established that under optimum weather and soil conditions, effective weed control may be obtained with doses of herbicide below that recommended by the manufacturer (Brain *et al.* 1998). But when applied in mixture its efficacy decreased to 96%. The ED_{50} value was estimated as 39.8 g/ha from the fitted model when used alone but it was increased to 45.7 g/ha when used in mixture (**Figure 2b**). Therefore, efficacy of the fenoxaprop decreased due to antagonistic effect of metsulfuron when applied in mixture.

On the other hand, metsulfuron controlled all broad-leaved weeds significantly even at the lower

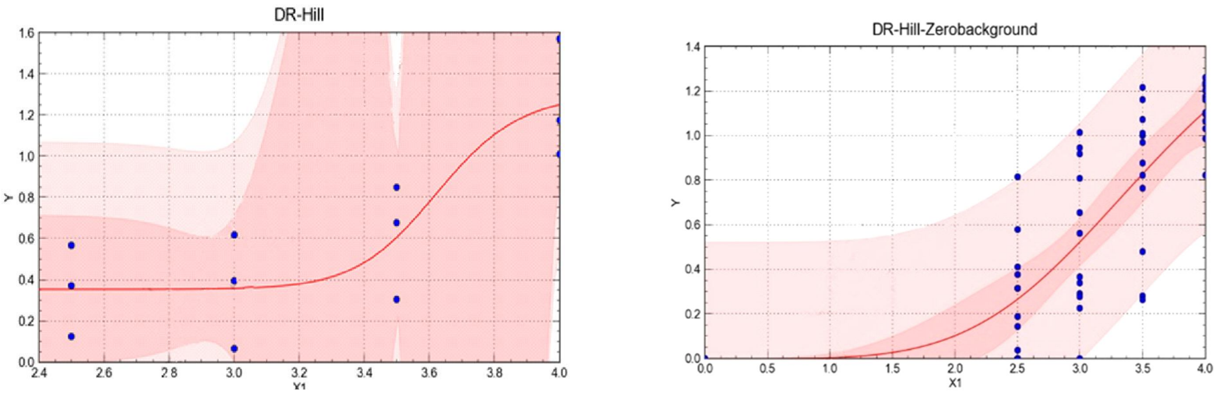
Table1. Parameters of the Hill models fitted to the data of fenoxaprop

Year	Herbicide	Parameter value			
		δ	α	θ	φ (ED_{50})
2013	Fenoxaprop (alone)	-	0.726	57.06	49.71
	Fenoxaprop (mixture)	-	0.85	4.05	44.9
2014	Fenoxaprop (alone)	0.221	1.54	49.4	39.8
	Fenoxaprop (mixture)	0.062	1.28	9.58	45.7



(a) $y = \frac{1.37x^{1.58}}{1.68^{1.58}+x^{1.58}}$ (b) $y = \frac{1.42x^{5.28}}{2.94^{5.28}+x^{5.28}}$

Figure 3. Dose response curve of weed control data (arc sine value) obtained from experimental plots where metsulfuron alone (a) or in mixture (b) was used to control broad leaved weeds in DSR during *Kharif* 2013



(a) $y = 0.335 + \frac{1.25x^{33.02}}{3.43^{33.02}+x^{33.02}}$ (b) $y = \frac{1.22x^{4.7}}{3.62^{4.7}+x^{4.7}}$

Figure 4. Dose-response curve of weed control data (arc sine value) obtained from experimental plots where metsulfuron alone (a) or in mixture (b) was used to control broad-leaved weeds in DSR during *Kharif* 2014

doses (<4 g/ha) in 2013. Hill model was also used to fit the data of metsulfuron alone as well as in mixture **(Figure 3**).

Metsulfuron applied alone, controlled all broad-leaved weeds effectively even at the lower doses than recommended (4 g/ha). Its ED_{50} value was obtained as 1.68 g/ha when applied alone but increased to 2.94 g/ha when applied in combination with fenoxaprop (**Figure 3**). Hence, it can be inferred that fenoxaprop has some antagonistic effect on metsulfuron when applied in mixture. In 2014, when metsulfuron was applied alone, it controlled 95% of broad-leaved weeds and ED_{50} value was obtained as 3.43 g/ha. But, when it was applied in mixture with fenoxaprop, its efficacy reduced to 90% with ED_{50} value as 3.62 g/ ha. These results indicated antagonistic effect of fenoxaprop on metsulfuron when used in mixture.

Table 1. Parameters of the Hill models fitted to the data of *Kharif* 2014

Year	Herbicide	Parameter value			
		δ	α	θ	φ (ED_{50})
2013	Metsulfuron (alone)	-	1.37	1.58	1.68
	Metsulfuron (mixture)	-	1.42	5.28	2.94
2014	Metsulfuron (alone)	0.335	1.25	33.02	3.43
	Metsulfuron (mixture)	-	1.22	4.7	3.62

Responses of herbicides in terms of weed control were different in 2 years. This was due to variable composition of broad-leaved, grassy weeds and sedges in soil seed bank (Anwar *et al.* 2013). During 2013, fenoxaprop failed to control all grassy weeds at lower doses but the weed control efficiency increased from 68 to 73% when used in mixture. On the other hand, it controlledall grassy weeds at recommended dose as well as at lower doses during 2014. However, when it was tank-mixed with metsulfuron, its efficacy decreased to 96% which confirmed the antagonistic effect of metsulfuron over fenoxaprop.

During both the years of experimentation, the efficacy of metsulfuron decreased when used in mixture. This further showed the presence of antagonistic effect of fenoxaprop on metsulfuron when used in mixture. In both the years, ED_{50} value of both the herbicides were different, so it was not possible to combine the results and therefore results were presented separately.

It was concluded that fenoxaprop and metsulfuron showed antagonistic effect on each other when used as tank-mix combination. These results are useful for the farmers and researchers to know about the compatibility of these two herbicides in direct-seeded rice.

REFERENCES

Anwar MP, Juraimi AS, Mohamed MTM, Uddin MK, Samedani B, Puteh A and ManAzmi. 2013. Integration of agronomic practices with herbicides for sustainable weed management in aerobic rice. *The Scientific World Journal* **2013**: 12 doi:10.1155/2013/916408.

Brain P, Wilson BJ, Wright KJ, Seavers GP and Caseley JC. 1999. Modelling the effect of crop and weed on herbicide efficacy in wheat. *Weed Research* **39**: 21-35.

Buhler DD, Liebman M and Obrycki JJ. 2000. Theoretical andpractical challenges to an IPM approach to weed management. *Weed Science* **48**(3): 274-280.

Chauhan BS and Johnson DE. 2010.The role of seed ecologyin improving weed management strategies in the tropics. *Advances in Agronomy* **105**: 221-262.

Chauhan BS and Johnson DE. 2011. Row spacing and weed control timing affect yield of aerobic rice. *Field Crops Research* **121**(2): 226-231.

Chauhan BS. 2012. Weed ecology and weed management strategies for dry-seeded rice in Asia. *Weed Technology* **26**(1): 1-13.

Chauhan BS, Mahajan G, Sardana V, Timsina J and Jat ML. 2012. Productivity and sustainability of the rice-wheat croppingsystem in the Indo-Gangetic Plains of the Indian subcontinent:problems, opportunities, and strategies. *Advances in Agronomy* **117:** 315-369.

Friesen SLJ, Ferguson GM and Hall JC. 2000. Management strategies for attenuating herbicide resistance: untoward consequences of their promotion. *Crop Protection* **19**: 891-895.

Goutelle S, Mourin M, Rougier F, Barbout X, Bourguignon L, Ducher M and Maire P. 2008. The Hill equation: a review of its capabilities in pharmacological modelling. *Fundamental & Clinical Pharmacology* **22**: 633-648.

Green JM. 1991. Maximizing herbicide efficiency with mixtures and expert systems. *Weed Technology* **5**: 894-897.

Kudsk P. 2002. Optimising herbicide performance. R.E.L. pp. 323-344. In: *Weed Management Handbook*, Naylor (Ed.), Blackwell Science, Oxford,

Mahajan G and Chauhan BS. 2011. Effects of planting pattern and cultivar on weed and crop growth in aerobic rice system. *Weed Technology* **25**(4): 521-525.

Mahajan G, Chauhan BS, Timsina J, Singh PP and Singh K. 2012. Crop performance and water- and nitrogen-use efficiencies in dry-seeded rice in response to irrigation and fertilizer amounts in northwest India. *Field Crops Research* **134**: 59–70.

Nyffeler A, Gerber HR, Hurle K, Pestemer W, and Schmidt RR. 1982. Collaborative studies of dose-response curves obtained with different bio-assay methods for soil-applied herbicides. *Weed Research* **22**: 213-222.

Pannell DJ. 1990. An economic response model of herbicide application for weed control. *Australian Journal of Agricultural Economics* **34**: 223-241.

Price WJ, Shafii B and Seefeldt SS. 2012. Estimation of dose–response models for discrete and continuous data in weed science. *Weed Technology* **26(**3): 587-601.

Sattin M, Campagna C and Marchi A. 2000. Herbicide resistance phenomena in Italy. *Informatore Fitopatologico* **7–8**: 33-34.

Seefeldt SS, Jensen JE and Fuerst EP 1995. Log-Logistic analysis of herbicide dose-response relationships. *Weed Technology* **9**: 218-227.

Singh S, Ladha JK, Gupta RK *et al*. 2007. Evaluation of mulching, intercropping with *Sesbania* and herbicide use for weed management in dry-seeded rice (*Oryza sativa* L.). *Crop Protection* **26**(4): 518-524.

Streibig JC.1987. Joint action of root-absorbed mixtures of auxin herbicides in *Sinapis alba* L. and barley (*Hordeum vulgare* L.). *Weed Research* **27**(5): 337-347.

Streibig JC and Jensen JE. 2000. Action of herbicides in mixtures. Chapter 7 pp. 153-180. In: *Herbicides and their Mechanisms of Action* (Eds: Cobb, AH and Kirkwood, RC), Sheffield Academic Press Ltd., Sheffield, UK.

Streibig JC, Rudemo M and Jensen JE 1993. Dose-response curves and statistical models. pp. 29-55. In: *Herbicide Bioassays* (Eds: Streibig JC and Kudsk P), CRC Press, Boca Raton, Florida, USA.