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Relative Efficacy of Herbicides for Weed Control in Rice: A Review

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A B S T R A C T

Rice farming is generally practiced in warm/cool humid subtropics where lack of control over the water by both flooding and drought problems and serious weed infestation thus crop badly suffer. Worldwide, weeds are one of the major biological threats to higher rice productivity and its management in rice is challenging, complex, expensive, and regulated mechanism. Therefore, to control the diverse weed infestation in rice fields, planed weed management strategies have to addressed. Now a day, unavailability of labour due to seasonal migration and lack of farm operations in the peak of the rice growing period adds fossil to the burning complications "the profuse weed infestation" and hence, the precise weed removal/control is utmost required to optimize the yield sustainability and efficient resource use. Among all the weed control methods, chemical weed control is commonly used to overcome weeds infestation which is easy, quick, time saving, cost effective and the most reliable method to control weeds in rice. In view of the limitations of herbicidal resistance of old molecules, it is necessary to promote the potential new molecules of herbicides and their combination (a sustainable option in a long run) for effective weed control. Among the existing herbicides, pre emergence herbicides alone are extensively used for controlling the rice weeds which do not provide extended period of weed control. To control weeds during the critical period of crop weed and escape the development of resistance, a combination of different groups of herbicides having different mode of action to be applied. Integrated approaches for weed management, emphasizing on the combination of management practices and scientific knowledge, may also reduce the economic costs and improve weed control owing to the complexity of the weed community.

Introduction

Rice (*Oryza sativa* L.) is one of the most important field crops after wheat in the world providing staple food to the millions. It is an indispensable source of calories for almost half of the population in Asia. More than 90% of the world rice is produced and consumed in Asia, which is a native for 60% of the earth's population. With the increasing food demand by the growing population, rice will continue to be primary source of food. Rice is primary food crop of India and therefore, national food security system largely depends on productivity of rice ecosystems. The world's total area under rice is 161.1 mha and production is about 480.3 mt along with the productivity of 2.98 t/ha (Statista-The statistics portal, 2017). Rice is the first most important crop in India where it is grown in an area of 44.1 mha with an annual production of 106.7 mt and average productivity is 2.4 t/ha. However, in Bihar, rice is being cultivated on 32.2 lakh ha area with the production of 64.89 lakh tonns having productivity 2.02 t/ha (Directorate of Economics Statistics, Govt. of India, 2017).Rice is grown in both *kharif* and *Rabi* seasons under diverse ecological and climatic conditions apart from socio-economic diversities of the state. 33% of total rice land has got irrigation facilities and rest is totally dependent upon rainfall. Among various depressing factors, abiotic stress i.e. water and nutrient stress and biotic stress i.e. weed infestations in the field are the most crucial factors due to which rice production is unpredictable and considerably low.Weeds not only reduce rice production but also have an adverse effect on rice grain quality. Hand weeding is the most effective method, however, high labour wages and non-availability of labour during peak periods of agricultural operations, timely weeding is not possible. Most of the pre-emergence herbicides viz., butachlor, pretilachlor and thiobencarb were applied in large quantities for weed management in transplanted rice. These herbicides are very effective for grasses and less effective against sedges and broad-leaved weeds (Singh *et al*., 2009). Further, these herbicides are very effective for controlling weeds up to 20 DAT. Application of herbicide mixtures or sequential application of herbicides may be useful for broad-spectrum control of weeds in rice. Recent trend of herbicide use is to find out an alternative and effective weed management by using low dose high efficiency herbicides, which will not only reduce the total volume of herbicide per unit area, but also application becomes easier and economical to the farmer.

Losses due to weed

Weed competes with the crop plants in the field for nutrients, moisture and sunlight. The nature and severity of weed competition depend on (a) types of weed species, (b) intensity of infestation, (c) duration of weed infestation, (d) competing ability of the crop plants and (e) soil-climate conditions which affect the crop and weed growth. Reduction in grain yield is directly correlated with the severity of weed competition. The prominent weed flora appearing in the rice field at different stages of crop growth under varied environmental situation differed because different species of weed flora required different agro-ecosystem. Grassy weeds were heavy competitors with rice crop and were followed by sedges and broad leaved weeds (Umapathy and Sivakumar, 2000). Kumar *et al.*, (2010) reported that the reduction in grain yield of rice due to uncontrolled weeds in weedy plot was 70.4 % during 2006 and 67.4 percent during 2007 as compared to weed control treatments. Puniya *et al.,* (2007) noticed that the highest loss of nutrients were occurred in unweeded (42.07, 10.00 and 21.80 kg NPK/ha) due to more density and dry weight of weeds in rice during *kharif*in silt loam soil of Pantnagar.

Research work done in India and abroad for weed control in rice by herbicides

Effect of herbicides on weeds in rice field

Herbicides effectively controlled the weed population and lowering weed dry matter production and it increase slowly towards maturity of the crop due to suppression of weed population at early stage of crop growth because of their broad spectrum activity that controlled most of the weed species. Hussain *et al.,* (2008) carried out a field experiment at Lahore, Pakistan. They found that bispyribac-sodum proved the best weedicide with 90.5 %

weed control efficiency and paddy yield with 3.61 t/ha which was comparatively higher than other weedicides. Dixit and Varshney (2008) conducted a field trail to evaluate the post-emergence herbicides in direct seeded rice during the rainy season of 2001 and 2002 and reported that the post-emergence application of Pyrazosulfuron 25 g/ha effectively controlled the infestation of *Phyllanthus niruri, Alternanthera sessilis, Commalleina bengalensis, Physalis minima* and *Cyperus iria* followed by one hand weeding. Incorporation of dhaincha by spraying 2, 4-D resulted in 78% reduction in total weed count and 59 % in weed dry matter production. Application of 2, 4-D for incorporation of dhaincha controlled broad-leaved weeds and sedges substantially (Anitha *et al.,* 2010). Shahbaz *et al.,* (2018) found that the weed density was influenced by different herbicides in transplanted rice and showed significant differences at three locations during *kharif* 2015. All the treatments significantly suppressed the weed density as compared to weedy check at all the locations. The highest numbers of weeds/m2 were recorded in weedy check (91.00, 67.34 & 56.30) while the lowest weed populations were recorded in the plot treated with bispyribac sodium (7.66, 3.67 & 5.60) at all the three locations respectively. Vaishya and Tomar (2000) reported that post-emergence application of 2,4-D @0.4kg/ha was formed promising in reducing the weed dry weight/unit area.

Effect of herbicides on growth and yield of rice

Growth and yield also significantly influenced by herbicides. This might be due to reduced state of crop-weed competition during critical growth stages. The plant did not face either the nutrients or moisture deficits caused by heavy weed infestation and enjoyed weed free condition during its peak vegetative and developmental phases. They grew freely to receive enough sunshine for carbohydrate synthesis resulting in better growth of plant, increased leaf area index, longer ear head, more number of effective tillers, more number of filled grains/spike and higher test weight. These ultimately resulted in increased grain yield of hybrid rice, Singh and Pandey (2019). The reduction of grain yield in weedy check was possibly due to severe weed infestation in the crop field. The weeds growing freely attained a vigour enough to complete with the crop plant for nutrient, moisture and sun-light throughout the growing season and thus suppress the crop plant resulted in reduced crop yield to greater extent Singh and Pandey (2019). These results are corroborated with findings of Kumar *et al.,* (2013) and reported that plant height of transplanted rice was significantly higher with the application of bispyribac sodium 30 g/ha than other herbicides and weedy check. Ali *et al.,* (2018) found that CGR, dry matter accumulation as well as LAI were high with the application of bispyribac sodium 25g/ha than butachlor as well as mechanical and hand weeding throughout the crop period. Kumar *et al.,* (2017) reported that among herbicides, significantly higher plant height, and dry matter accumulation were recorded in pyrazosulfuron *fb* bispyribac Sodium (150 g/ha PE fb 25g/ha POE) than weedy check. Dixit *et al*., (2010) concluded that, the chemical weed control effectively controlled weeds were till the advanced growth stages of rice, which reduced weed competition favoring better utilization of available resources and it increases the grain and straw yield of crop.

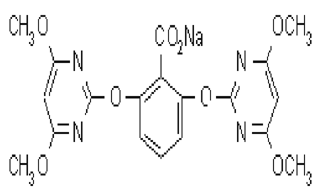
Effect of herbicides on nutrient uptake by rice

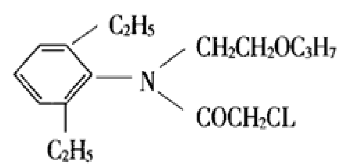
Nutrient uptake by the rice is affected by the nutrient content in the total dry matter accumulated by the crop in its life cycle. This was fact that effective weed control measure increased the uptake of nutrients by the crop and decreased their removal by weeds. Finally the weed free crop absorbs higher quantity of nutrient from the soil than weedy check. However, in chemical weeding systems, lower depletion was recorded at early stage when steadily increased towards later stages of crop growth. Because of their persistence in soil, it controls the weeds over an extended period of time. As the degradation of herbicides occurs due to various chemical and bio-chemical processes, the killing effect also tend to decrease resulted in accumulation of high dry matter later stages of crop growth. Some finding was confirmed by Devi and Singh (2018) reported that among weed management practices, application of bispyribac at 25 g/ha + azimsulfuron at 17.5 g/ha at 15-20 DAS established their superiority in minimizing the nitrogen removal by weeds which was significantly superior to other weed management treatments but it was next best to the hand weeding twice at 20 and 40 DAS. Kumar *et al.*, (2010) found that uptake of nutrients was higher by direct seeded rice crop and decreased nutrient uptake by weeds with hand weedings and pre-emergence application of pendimethalin @1.0 kg/ha +anilophos @0.4 kg /ha over rest of the treatments.

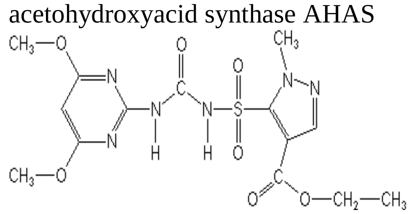
Table.1 Weeds flora in rice field

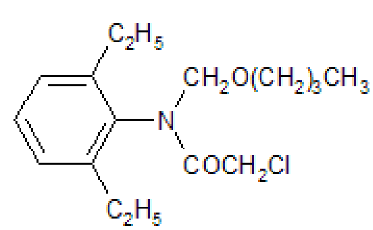
Weeds	Botanical name	English name	Common name	Family	Habitat
Grasses	*Cynodondactylon*(L.) Pers	Bermuda grass	Doob grass	Poaceae	Perennial
	Echinochloacrusgalli(L.) Beauv	Barnyard grass	Shymaghas	Poaceae	Annual
	Echinochloacolonum(L.) Link	Jangli rice	Senwai/ Dhenhari	Poaceae	Annual
	Eleusineindica(L.) Gaerth	Goose grass	Kodai	Poaceae	Annual
	Digitariasanguinalis(L.) Scop.	Crab grass	Hindu Behar	Poaceae	Annual
	Dactylocteniumaegyptium(L.) P. Beauv	Crow foot grass	Makaraghas	Poaceae	Annual
	Oryza sativa	Weedy rice	Weedy rice	Poaceae	Annual
	*Panicumrepens*Linn.	Panic grass	Debhar	Poaceae	Annual
	*Paspalumdistichum*L	Hiiograss/Knot grass	NaadiGhas/Badidoob	Poaceae	Perennial
Sedges	*Cyperusrotundus*Linn	Purple nut sedge	Motha	Cyperaceae	Perennial
	*Cyperusiria*Linn	Yellow nut sedge	Bhada	Cyperaceae	Perennial
	*Cyperusdifformis*Linn	Paddy motha	Jhirua	Cyperaceae	Perennial
	Fimbristylismiliaceae(L.) Vahl	-	Banchitra	Cyperaceae	Perennial
Broad-leaved weeds	*Amaranthusviridis*Linn	Pigweed	Janglichaulai	Amaranthaceae	Annual
	Ammanniabaccifera(L.) Roxb	Red stem	Janglimehandi	Lythraceae	Annual
	Caesulia axillaries (L.) Rottb	Ghrilla	-	Compositae	Annual
	*Commelinabenghalensis*Linn	Day flower	Kankaua	Commelinaceae	Annual
	Eclipta alba (L.) Hassk	Mukand	Bhangra	Compositae	Annual
	*Euphorbia hirta*Linn	Asthma plaub	Bari doodhi	Euphorbiaceae	Annual
	*Phyllanthusniruri*Linn	Hazardana	-	Euphorbiaceae	Annual
	*Ludwigiaparviflora*Linn	-	Water purslane	Onagraceae	Annual
	SpilanthesacmellaMurr.	-	-	Asteraceae	Annual

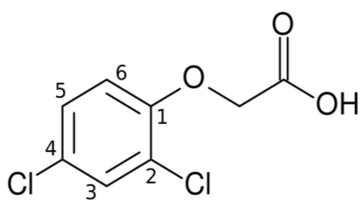
Description of herbicides use in rice field

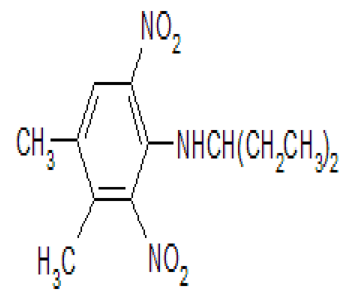
Common name	:	**Bispyribac-sodium**
Substance group	:	Pyrimidinylcarboxy compound
Chemical formula	:	$C_{19}H_{17}N_4NaO_8$
Substance origin	:	Synthetic
Chemical name	:	Sodium 2,6-bis [4, 6-dimethoxypyramidin-2-yl) oxy]
Trade name	:	Nominee gold
Formulation and Active ingredient	:	Soluble concentration (10 %)
Time of application	:	Post-emergence (20-25 DAT)
Type of Herbicide	:	Systemic
Mode of action	:	Selective, systemic action absorbed by foliage and roots. Inhibits plant amino acid synthesis - acetohydroxyacid synthase AHAS.
Structural Formula		

Common name	:	**Pretilachlor**
Substance group	:	Chloroacetamide
Chemical formula	:	$C_{17}H_{26}CINO_2$
Substance origin	:	Synthetic
Chemical name	:	2- Chloro-N- 92.6 diethyl phenyl) –N- (2-propoxyethyl) acetamide
Trade name	:	Rifit
Formulation and Active ingredient	:	Emulsion Concentrate (50%)
Time of application	:	Pre-emergence (0-5 DAT)
Type of Herbicide	:	Systemic
Mode of action	:	Selective, systemic action herbicide. Control annual grasses, broad-leaved weeds and sedges in rice and works by inhibiting cell division.
Structural Formula		

Common name	:	**Pyrazosulfuron**
Substance group	:	Sulfonylurea
Chemical formula	:	$C_{14}H_{18}N_6O_7S$
Substance origin	:	Synthetic
chemical name	:	Ethyl 5 [N (4,6dimethoxypyrimidin2yl) carbamoyl-sulfamoyl]1-mthyl-1H-pyrazole-4-carboxylate
Trade name	:	Sathi
Formulation and Active ingredient	:	Wettable powder (10 %)
Time of application	:	Post-emergence (20 -25 DAT)
Type of Herbicide	:	Systemic
Mode of action	:	Broad-spectrum activity absorbed by roots and translocated throughout plant by controlling the synthesis of amino acids. Inhibits plant amino acid synthesis - acetohydroxyacid synthase AHAS
Structural Formula		

Common name	:	**Butachlor**
Substance group	:	chloroacetamide
Chemical formula	:	$C_{17}H_{26}ClNO_2$
Substance origin	:	Synthetic
chemical name	:	N-butoxymethyl- 2 Chloro-2, 6-diethyl acetanilide
Trade name	:	Machete
Formulation and Active ingredient	:	Emulsion Concentrate 60% (w/v), Granule (5%)
Time of application	:	Pre-emergence
Type of herbicide	:	Systemic
Mode of action	:	Selective, systemic absorbed primarily via germinating shoots. Inhibition of VLCFA (inhibition of cell division) control of annual grasses and some broad-leaved weed.
Structural Formula		

Common name	:	**2, 4- D**
Substance group	:	Chlorophenoxy compounds
Chemical formula	:	$C_8H_6Cl_2O_3$
Substance origin	:	Synthetic of auxin
chemical name	:	2, 4-Dichlorophenoxy acetic acid ethyl ester
Trade name	:	Barrage, Formula 40, Opt- amine, Weedar 64, Plantgard and weedmar
Formulation and Active ingredient	:	Emulsion Concentrate (38%), Dark amber liquid
Time of application	:	Post-emergence
Type of Herbicide	:	Systemic and Selective
Mode of action	:	It is penetrate foliage, whereas plant roots absorb the salt forms used on a wide variety of terrestrial and aquatic broadleaf weeds. It has little effect on grasses. Abnormal increases in cell wall plasticity, biosynthesis of proteins, and production of ethylene occur in plant tissues following exposure, and these processes are responsible for uncontrolled cell division.
Structural Formula		

Common name	:	**Pendimethalin**
Substance group	:	Dinitroaniline
Chemical formula	:	$C_{13}H_{19}N_3O_4$
Substance origin	:	Synthetic
chemical name	:	N-(1-ethylpropyl)-2, 6-dinitro-3, 4-Xylidine
Trade name	:	Stomp
Formulation and Active ingredient	:	Emulsion Concentrate (33 and 40%),
Time of application	:	Pre-emergence, Post-emergence
Type of Herbicide	:	Systemic and Selective
Mode of action	:	Selective, absorbed by roots and leaves and control annual grasses. Inhibition of mitosis and cell division. Microtubule assembly inhibition
Structural Formula		

Effect of herbicides on economics of rice

Chemical weed control always cost effective than other method of weed controls this might be due to less cost involved in chemical treatment per unit of yield obtained. It was observed that although, the yield was higher in hand weeded plot, the net return and B: C ratio was higher in chemical weeding (combined application of bispyribac-sodium + pyrazosulfuron). It was the cost investment in hand weeding which caused such differences. These findings were in agreement with Kaur and Singh (2015) and Juraimi *et al.*, (2013). Hand weeding twice is still the most effective means to manage weeds in most of the crops but ever increasing efficacy of newly evolved herbicides and still faster increasing labour cost, making manual weeding a less desirable option. The also find support with the works of Kumaran *et al.*, (2015) adoption of different weed management practices significantly influenced the gross returns, net returns and B:C ratio. The treatment consisting of bispyribac sodium 10% SC 40 g/ha registered Rs. 60,698 per ha as gross income next to weed free check Rs. 63,217 per ha with a net return of Rs. 38,970 per ha and a B: C ratio 2.79. This was followed by pretilachlor at 0.45 kg/ha + HW on 40 DAS with a gross return of Rs. 60,064 per ha, net return Rs. 36,171 per ha and B:C ratio 2.51.Das *et al.*, (2017) concluded that the post-emergence application of bispyribac-sodium 25 g/ha at 25 DAT proved economical herbicide for transplanted rice as compared to hand weeding twice and also other herbicides and weedy check. Singh and Namdeo (2004) found higher net return (₹17,660 / ha) and B:C ratio (2.57) under two hand weedings, which reduced to ₹ 9,847 / ha and 2.26 under the application of butachlor. Also butachlor +

2, 4-D (EE) was comparable to two hand weedings wherein the net return and B: C ratio was observed to be ₹ 11,435/ha and 2.41.

In conclusion, weeds being the extreme serious pests in agriculture and have the excessive ability to compete with the crop for available resources (space, light, nutrient, CO_2, water, air and etc.). Weed control in rice crop is always a problematic task for effective crop production as their presence causes severe reduction in yield and quality of crops thus reducing yield productivity and profitability. Herbicide applications is commonly used to overcome weed infestation which is easy, quick, time saving, cost effective and it is most reliable method to control weeds. Rice is grown in diverse agro-ecosystem therefore, weed communities and its types associated to rice fields are having huge variations. Hence, the use of a single herbicide cannot give satisfactory and cost-effective results of weed control. Integrated strategies on chemical weed management is the best option to control the diverse weeds flora and the competitive ability of weeds for the above and below ground resources. Regular monitoring and early detection of the evolution and mechanism of herbicide resistance is necessary. The adoption of suitable management strategies on herbicide is utmost important. Hence, in the future, researchers need to develop integrated weed management strategies along with effective herbicides which do not only favor crop yield and reduce weed infestation but also discourage the resistance of weed flora to herbicides.

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