Integrated Weed Management (IWM) for Sustainable Agriculture – A Review

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Abstract**—** *Weeds are defined as any growing plant infield, where it is not wanted and weeds are also used as feed for the animals. Weeds are creating a big problem in agriculture by reducing the growth and development of crops and minimizing the yield of the crops. Weeds are the major problem in agriculture therefore management practices require increasing the yield of the crops. Sustainable agriculture is defined as a farming system that meets foods for the present population by reducing the use of chemicals. Integrated weed management (IWM) is defined as a process that synchronizes the use of major and minor information on the environment, ecology, and biology of weeds, and ecologically controlling the weeds from fields. Yield losses in soybean may range from 25 to 70 %, 40-80 % in onion, 40-70% in maize, 40-50% in rice, and 25-50% in wheat depending upon the intensity and infestation of weeds. Rice residues as mulching at 6 and 7 t/ha and adding post-emergence herbicides like clodinafop 60 g/ha, sulfosulfuron 25 g/ha, and mesosulfuron+iodosulfuron 14.4 g/ha were found more effective to control weeds like P. minor and also board leaf weeds from the wheat field. Zero tillage is generally done in wheat crops and also in maize crops to minimize of cost of cultivation. The incorporation of daincha and azolla in a field generally increases the yield of the crops during the early stages.*

Keywords— Integrated weed management (IWM), Losses, Components, and Herbicides.

I. INTRODUCTION

Integrated weed management (IWM) is a management system that's approach on required awareness of implementation on a crop for its good health. They view it as a series of interactions among several weed control components (Swanton *et al*. 2008). Integrated weed management (IWM) is the process that synchronizes the use of major and minor information of environment, ecology, and biology of weeds, and ecologically controlling the weeds from fields by using all available technology. Integrated weed management (IWM) research are focusing on the process of decision-making, ecology and biology of weeds, components of IWM which are generally practiced on cropping pattern, resistance level of herbicide, ecology problem related to transgenic plants, and weeds welfare (Rao and Nagamani, 2010). Integrated weed management (IWM) is defined as a collecting environmental information, ecology and biology of weeds using all available technology for

controlling the weeds (Sanyal, 2008). IWM focuses on reduction of weeds in a single or multiple season and also use the broadcast-type equipment for controlling of weeds. In traditional methods, puddling is done for the killing of weeds and aid water retention and also for the transplanting of rice (Rao *et al*., 2007). From a biological approach, successfully integrating weed management requires an understanding of three key components: the effect of treatments on weed populations, weed growth and development stages and the critical period for applying control tools (Swanton *et al.*, 2008). Control tools (e.g. mowing, spraying, cultivating) have differing effects on weeds, and without a complete understanding of the life history of the target weed(s) and crop, the development of effective and efficient robotic systems will be extremely challenging, if not impossible. In all crops, there exists a period in which weed control is critical to avoid incurring yield loss (Knezevic *et al.*, 2002). Combining recognition and application technology into a single platform for fast and efficient weed control across spatiotemporal scales will require precise information on weed biology and ecology and continued testing of technology for a wide range of field conditions (Slaughter *et al.*, 2008; Singh *et al.*, 2011). Considering the diversity of weed problem and agro-ecosystems, no single method of weed control could reach the desired level of efficiency under all situations (Singh 2010). Thus, IWM has been suggested as a sustainable and long-term management technique.

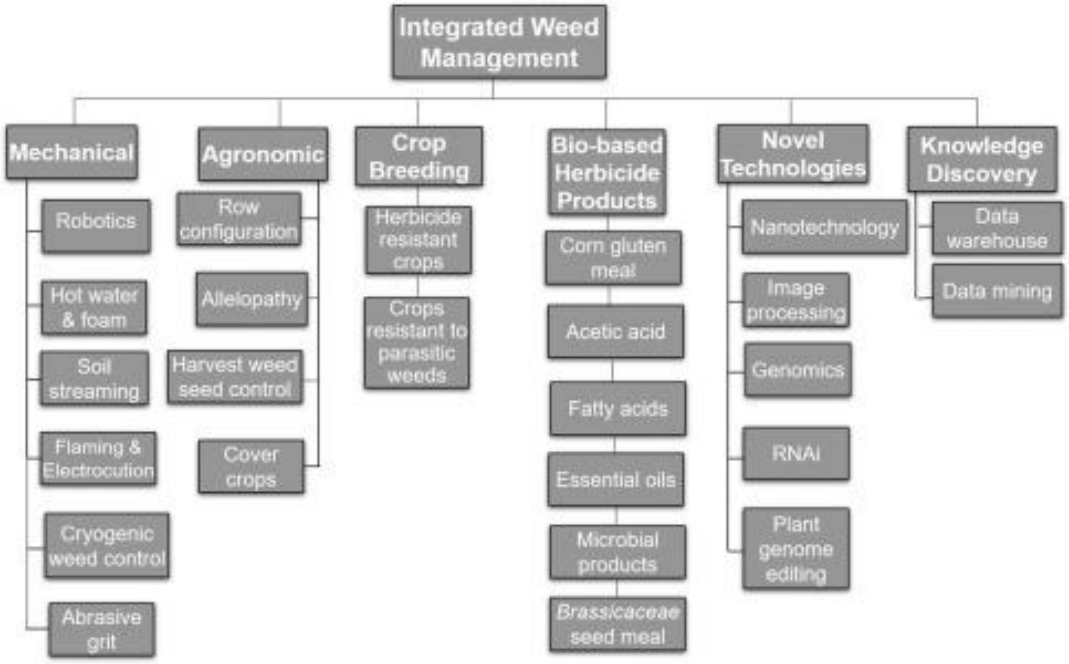

FIGURE 1: Components of Integrated weed Management (IWM)
Source: Nicholas et., al. 2019

II. YIELD LOSSES DUE TO WEED COMPETITION

In rice crops, about 350 weed species having 150 genera and 60 plant families are found as weeds, and more than 80 species of Gramineae are reported as weeds in a rice field. The most common weed species of rice are *Echinochloa crusgalis, E. colonum, Cyperus difformis, C. rotundus, C. iria, Eleusine indica, Fimbristylis miliacea, Ischaemum rugosum, Monochoria vaginalis, and Sphenoclea zeylanica.* The presence of these weeds species creates major problems in the rice field. Seeding method, soil moisture, crop rotation, air and soil temperature, land preparation, fertilization, rice cultivar, and weed control technology are the best methods for controlling weeds. The presence of weeds reduced the production of rice and as well as reduced the quality of the rice crop. Losses caused by weeds are influenced by competitive efficiency of weeds and rice, species or group of weed, weed density, duration of the weed-crop competition, planting method, cultivar, fertility level, water management, row spacing of the crop, allelopathy.

TABLE 1
MAJOR WEEDS WHICH ARE FOUND ON THE FIELD OF PULSES

Season	Type of weeds	Name of weeds
Kharif pulses	Non -grasses	*Digeraarvensis, Commelinabenghalensis, Celosia argentea, Cucumistrigonus, Trianthemamonogyna, Euphorbia hirta*
	Grasses	*Digitariasanguinalis, Cynodondactylon, Panicum sp. Echinochloacolonum, Dactylocteniumaegypticum, Setariaglauca, Eleusineindica*
	Sedge	*Cyperusrotundus*
Rabi pulses	Non -grasses	*Chenopodium album, Solanumnigrum, Anagallisarvensis, Vicia sativa, Fumariaparviflora, Asphodelustenuifolius, Convolvulus, Melilotusindica, Medicago denticulate*
	Grasses	*Phalaris minor, Avenaludoviciana*
	Sedges	*Cyperusrotundus*
Zaid/Summer pulses	Non-grasses	*Chenopodium album, Amaranthusviridis, Portlacaquadrifida, Trianthemamonogyna*
	Grasses	*Setariaglauca, Cynodondactylon, Eleusineindica, Digitariasanguinalis, Panicummaxicum*
	Sedges	*Cyperusrotundus*

Source: 25 Years of Pulses Research at IIPR

TABLE 2
CRITICAL PERIOD OF WEED COMPETITION FOR IMPORTANT CROPS.

S.N.	Crops	Days from sowing	S.N.	Crops	Days from sowing
1	Rice (lowland)	35	7	Cotton	35
2	Rice (upland)	60	8	Sugarcane	90
3	Sorghum	30	9	Groundnut	45
4	Finger millet	15	10	Soyabean	45
5	Pearl millet	35	11	Onion	60
6	Maize	30	12	Tomato	30

In India, presence of weeds in general reduces crop yields by 31.5 and 22.7% in winter season and 36.5% in summer and kharif season and in some cases can cause complete devastation of the crop (Anonymous, 2007). Yield losses in soybean may range from 25 to 70 percent depending upon the intensity and infestation of weeds. Besides yield losses, quality also adversely affected. The most critical period of weed infestation is initial 15-45 days (Kale, 1985). Weeds are major problems for crops cultivation its generally reduces the growth and development of the crops. In the field of onion, 40-80 %yield is reduced due to infestation of weeds (Channapagoudar and Biradar, 2007). The yield losses found highest at unweeded plots of the rice-wheat system, but it was lower at sugarcane system (Singh *et al*., 2005a). The prevention from yield losses should be done during crops growth cycle by reducing weeds from the field at critical period. Production losses may also occur due to weeds as 33.16% in food crops, 41.26% in cereals, 31.88% pulses, 40.82% in oilseeds, 34.23% in fibre crops and 40.28% in rice crops in the country. However, an average of 13.1% of crop produce is actually lost in the farmers field even after adopting traditional weed controls in Bangladesh.

TABLE 3
YIELD LOSSES DUE TO WEEDS IN MAJOR CROPS.

Crops	Reduction in yields due to weeds (%)	Crops	Reduction in yields due to weeds (%)
Rice	41.6	Groundnut	33.8
Wheat	16.0	Sugarcane	34.2
Millets	29.5	Sugar beet	70.3
Soyabean	30.5	Carrot	47.5
Gram	11.6	Cotton	72.5
Pea	32.9	Potato	20.1
Maize	39.8	Onion	68.0

Source: TNAU

The yield of grain was reduced by 25% to 47% and straw yield was reduced by 13% to 38% due to Crop weed competition. The infestation of weeds in a field reduced the content of soil nitrogen and phosphorus and also the pH level of the soil. The root, stem, and leaf of dominant weeds (Echinochloa colona, E. crus-galli, Cyperus iria, and Ageratum conyzoides) showed a weak effect on seeds germination however most of them had an inhibitory effect on root and shoot elongation of paddy seedlings. The weeds show more inhibition on the growth of paddy seedlings as compared to leaf and root.

TABLE 4
CRITICAL PERIOD OF CROP-WEED COMPETITION AND YIELD LOSSES DUE TO WEEDS IN PULSE CROPS.

Crops	Critical period (Days after Sowing)	Yield loss (%)
Pigeonpea	15-60	20-40
Mungbean	15-30	25-50
Urdbean	15-30	30-50
Cowpea	15-45	15-30
Chickpea	30-60	15-25
Fieldpes	30-45	20-30
Lentil	30-60	20-30
Frenchbean	30-60	15-30

Source: Yaduraju and Mishra (2004)

III. IWM WITH HERBICIDES AS A COMPONENT

Integrated weed management (IWM) is defined as using multiple methods for controlling weeds from the field with a combination of the most effective practices to control weeds. Prevention, Cultural, Mechanical, Chemical, and Biological are the practices used for Integrated weed management (IWM). A prevention method is defined as the equipment which is used in the field has contaminated with weed seeds. The primary spreaders of weeds are equipment, manure, feed, and crop seeds. The controlling of weeds should be done by cleaning all the equipment, which is used in crops field.

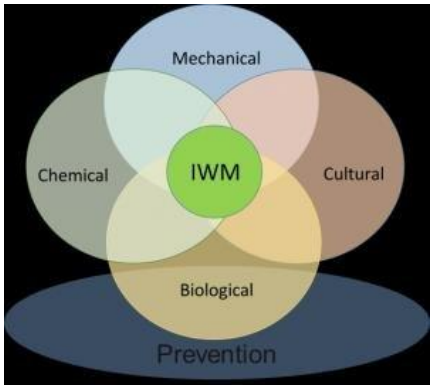

FIGURE 2: Management tactics used in integrated weed management (Annie Klodd)

The Cultural method is also used for controlling weeds and is found more effective as compared to chemicals. The crop management decisions help in controlling weeds and help in optimizing the effectiveness of chemical applications. Timely scouting, row spacing, crop rotation, crop variety selection, the timing of planting, and cover cropping are the best practices

that are used for controlling weeds in the Cultural method. Cultivation, tillage, burning, Puddling, and hand-weeding are the practices of mechanical management of weeds. Emerging technologies like harvest-time seed destructors, cover crop rollers, and robotic weeders are also used in controlling weeds through the mechanical method. The use of living organisms, including livestock, insects, nematodes, fungi, and bacteria are used in the Biological method for controlling weeds from the crop field. The biological method is eco-friendly in controlling weeds.

TABLE 5

HERBICIDES USED FOR CONTROLLING WEED SPECIES AND THEIR TOXICITY LEVEL AND MODE OF ACTION.

Herbicide	Mode of action	Weeds controlled and use	Toxicity	Warnings
Buster	Systemic contact herbicide (via the leaf). No residual life in the soil.	Grasses, broadleaved weeds and clovers. Provides short-term weed control	Poison.	Avoid contact with desirable plants and immature bark.
Gallant NF	Emulsifiable concentrate. Half-life in the soil of less than 24 hours	Selectively controls grasses. Can be mixed with Versatil, Gardoprim or Simazine for controlling clovers and broadleaved weeds.	Harmful substance.	Immediately after use, flush sprayer several times with clean water.
Glyphosate Roundup, Renew	Absorbed through foliage and translocated to all parts of the plant, including roots. Half-life <14 days in aerobic soil, and 14-22 days in anaerobic conditions.	Controls most annual and perennial grasses and broadleaved weeds. Used as a pre-planting or a release spray. Can be used successfully as a stump poison.	Low toxicity.	Spray drift must not contact foliage or green-bark of desirable trees.
Interceptor (Organic spray - new product with limited information on weed control in establishing native plants)	Emulsifiable, non-selective, contact foliage spray. Penetrates green plant tissue, and disrupts cellular physiology. Fast acting (within minutes) but may require additional treatment.	Controls annual weeds and grasses, and perennial weeds. Can be used as a pre-planting or release spray.	Low toxicity.	Spray drift may damage foliage, fruit or unprotected green bark of desirable plants. Also kills algae, mosses and liverworts.
Simazine	Absorbed only through roots of germinating plants. Soil residual life ranges from 3 - 12 months. Half-life varies from 27-102 days. Low leaching potential.	Prevents the emergence of a wide range of annual and perennial grasses and broadleaved weeds.	FlowableSimazine - poison. Others - low toxcicity.	Spray drift may cause serious damage to other plants.
erbuthylazine (Gardoprim)	Absorbed through roots and leaves. Pre- and post-emergent half-life in biologically active soils is 30 - 60 days.	Controls a wide range of annual and perennial grasses and broadleaf weeds. Apply pre-planting or as a release.	Hazardous substance	Follow manufacturers recommendations. Avoid using near desirable plants, where the chemical may be leached into their root region.
Versatil	Absorbed by leaves, stems and roots.	Controls thistles, yarrow, clovers and many difficult flat weeds. Can be mixed with other herbicides for the control of additional weeds. Do not apply to legumes or compositae (daisy family)	Harmful substance.	Follow manufacturer's recommendations. Remains active on plant material - do not use clippings from treated areas for compost or mulch, within 6 months of treatment.

Source: Department of Conservation

IWM found more effective when use of herbicides with following components. Which are given below:-

3.1 Crop Rotations, Cropping Systems and Herbicides

The crop rotation is defined as a cultivation of crops in specified order on the field for reducing weeds competations and increasing the yield of crops. And the cropping system is generally known as cropping pattern which minimize yield losses and provide better environmental conditions to the crops. Crop rotation and cropping systems both are component of IWM. The different cropping sequences failed to affect broadleaf weeds. Rice-lentil+mustard (3 : 1)-cowpea, rice-maize + pea (1 : 1)-cowpea and rice-potato-greengram gave high yield (Singh *et al*., 2008).

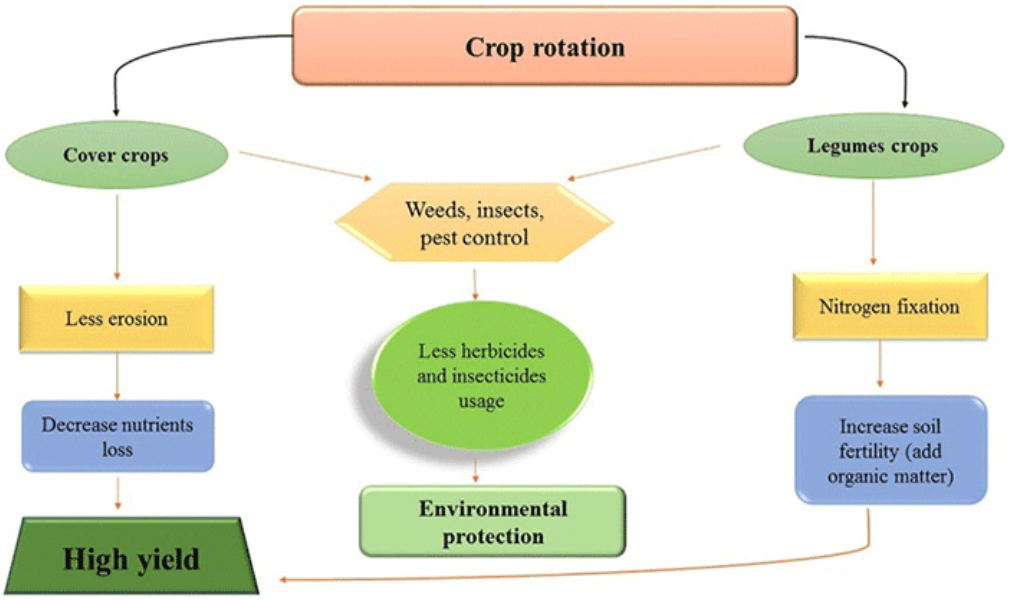

FIGURE 3

Source: Faisal Nadeem and Ahmad Nawaz et. al.

The reduction of weed density and dry weight of the field was achieved by effective weed control and intercropping with *Sesbania* (Dhaincha), and azolla with pretilachlor and safener at 400 g/ha found control against weeds (Subramanian and Martin, 2006). The incorporation of daincha and azolla in field generally increases the yield of the crops during early stages. The cropping sequence of mungbean-mustard giver higher yield (Singh, 2006).

TABLE 6

HERBICIDES WHICH ARE USED IN CROPPING SYSTEM FOUND BETTER WEED CONTROL.

Cropping System	Herbicides	Dose (kg ai/ha)	Trade Name & formulation	Time of application
Sorghum + Cowpea	Pendimethalin	0.90	Stomp 30% EC	Pre-emergence
Sugarcane + Pulses	Thiobencarb	1.25	Saturn 50% EC	Pre-emergence
Maize + Soybean	Pendimethalin	1.00	Stomp 30% EC	Pre-emergence

3.2 Tillage with Herbicides

Tillage is the best practice for the eradication of weeds from the field. The seeds of weeds are present in the fields and moving from field to field through tractor tires, and vegetative structures. The cultivation equipment like tractors and harvesters are moves seeds of weeds from field to field. The seeds of weeds are present in the depth of soil so tillage is used to remove weeds seeds from the field. In wheat cultivation, deep/inverted tillage with mouldboard plough and application of clodinafop @ 60 g/ha, sulfosulfuron @ 25 g/ha, and fenoxaprop ethyl @ 100 g/ha at post-emergence found effective control against *P. minor* (Walia *et al*., 2005).

TABLE 7
COMMON HERBICIDES USED FOR CONTROLLING WEEDS IN VEGETABLES AND FRUITS CROPS.

Chemical	Vegetables appearing on label	Weeds controlled	Timing of Application	Application rates
Burndown				
Glyphosate Trade name: Roundup®, other	Many crops; see label for specifics.	A non-selective herbicide that controls many weeds.	Pre-plant applications allowed in most plants. Post-directed and spot spray treatments are allowed for certain crops as long as care is taken to avoid contact with any foliage or green tissue. Consult label product labels for more specific information. Glyphosate has no soil residual activity	1 to 5 pints/acre or 1 to 10% solutions, depending on the crop Surfactant requirements are based upon formulation of glyphosate selected. Please consult label for specific recommendations.
Pelargonicacid Trade name: Scythe®, other	Asparagus, artichoke, beet, carrot, parsnip, potato, radish, sweet potato/ yam, turnip, rutabaga, garlic, onion, leek, shallot, celery, cilantrol, cress, endive, lettuce, parsley, rhubarb, spinach, broccoli, Brussels sprouts, cabbage, cauliflower, collards, kale, kohlrabi, greens (mustard and turnip), eggplant, okra, pepper (chili, bell, sweet), pimento, tomato, cucumber, gourd, muskmelon, cantaloupe, pumpkin, squash, watermelon, apple, pear, apricot, cherry, nectarine, peach, plum, prune, blackberry, blueberry, dewberry, grape, strawberry, grape and other fruits and vegetables	A non-selective herbicide that controls many weeds.	Post-directed (avoiding spray on foliage or green bark) and preplant applications in all landscape trees, bedding plants, flowers and other ornamentals. Pelargonic acid has no soil residual activity.	3 to 10% solution (spot spray): 3-5%-solution for annual weeds 5-7%-solution for perennial weeds 8-10%- Solution for maximum burn down of mature weeds No additional adjuvant required.
Pre-emergence				
Trifluralin Trade name: Preen™ Garden Weed Preventer	Many vegetable crops and non-bearing tree fruit and nuts *Not labeled for preemergence applications in cucurbit crops.	Several annual grasses, carpetweed, chickweed, Florida pusley, goosefoot, henbit, knotweed, lambsquarters, pigweed species, purslane	Pre-emergence weed control when applied to garden vegetables 2 to 3 inches tall but before weeds have emerged. However, application methods may differ with specific crops. This product needs immediate incorporation	1 lb / 400 sqft for heavy clay soils 1 lb / 960 sqft for medium loam soils 1 lb / 1280 sqft for light sandy soils

TrifluralinTrade name: Treflan® 4L, Treflan® EC, etc.	Many vegetable crops and non-bearing tree fruit and nuts *Not labeled for preemergence applications in cucurbit crops.	Several annual grasses, carpetweed, chickweed, Florida pusley, goosefoot, henbit, knotweed, lambsquarters, pigweed species, purslane	after application with irrigation, rainfall or light tillage. May be applied prior to planting or transplanting most vegetable crops. Immediate incorporation is necessary for optimal control. See label for more details.	1 to 2 pints/acre depending on crop and soil type (fine textured soils require the highest recommended rate, while coarse-textured soils require the lowest recommended rate)
Pendimethalin Trade Name: Prowl® H20	Carrots, sweet corn, edible beans, garlic, grain sorghum, lentils, mints, onions, peas, potato, sunflower and other vegetables	Several annual grasses, carpetweed, chickweed, Florida pusley, henbit, ladysthumb, common lambsquarters, pigweed species, purslane, spurge	Pre-plant incorporated or preemergence applications prior to planting or transplanting vegetable crops. Postemergence applications can be made in certain crops but weed control is dependent on applying prior to weed emergence.	1.5 to 4 pints/acre depending on crop and soil type (fine-textured soils require the highest recommended rate, while coarse-textured soils require the lowest recommended rate)
DCPA Trade name: Dacthal®, other	Broccoli, Brussels sprouts, cabbage, cauliflower, all Brassica leafy vegetables, cantaloupe/honeydew/watermelons (not preemergence but 3- to 5-leaf; do not incorporate), onions, radish (from preemergence up to 3-leaf stage), sweet potato, strawberry, tomato/tomatillos/ eggplant (4 to 6 weeks after transplanting or 4 to 6 inch tall seedling)	Several annual grasses, lambsquarters, carpetweed, chickweed, purslane, field pansy and suppression of other broadleaf weeds	Pre-plant or preemergence weed control	6 to 14 pints/acre or 4 to 5 floz/1 to 2 gallons (treats 1000 sq ft.
Post-emergence				
Sethoxydim Trade name: Poast®, other	apricot, asparagus, beans (dry, succulent), beets, broccoli, Brussels sprouts, cabbage, cauliflower, collards, garlic, kale, kohlrabi, leeks, mustard/ rape greens, cantaloupe, cucumber, honeydew, musk melon, pumpkins, watermelons, onions, radish, sweet potato, carrot, cherries, strawberry, grape, peppers, celery, lettuce, rhubarb,	Provides selective postemergence contact control of several grass species including, but not limited to, bermudagrass, broadleaf signalgrass, crabgrass spp., foxtail spp., goosegrass and johnsongrass.	Provides selective postemergence contact grass control only. Sethoxydim has little to no soil residual activity	1.5 to 2.5 pints/acre (depending on crop) Add 1% v/v crop oil concentrate.

	groundcherry, tomato, tomatillos, eggplant, raspberry, blackberry, lettuce, endive, parsley, spinach, mint, nectarine, peach, peanut, potato, plum apples, pears, peas (dry, succulent), artichoke, yam and other vegetables			
ClethodimTrade name: SelectMax®, other	Bean (dry), broccoli, cabbage, carrot, cauliflower (other head and stem Brassica), celery, cucumber, eggplant (other fruiting vegetables), garden beet, garlic, legume vegetables (garden podded), lettuce, melons (including cantaloupe and watermelon), mint, mustard greens, onion, pea, peanut, peppers, potato, pumpkin, radish, rhubarb, squash, strawberry, sunflower, sweet potato, turnip greens, tomato, yam (other tuberous and corm vegetables) and other vegetables	Provides selective post-emergence contact control of several grass species including but not limited to bermudagrass, broadleaf signalgrass, crabgrass spp., foxtail spp. and johnsongrass. Does not always adequately control goosegrass.	Provides selective post-emergence contact grass control only. Clethodim has little to no soil residual activity.	Annual grass weeds: 9 to 16 floz/acre Perennial grass weeds: 12 to 16 floz/acre Add 0.25% v/v nonionic surfactant.
Halosulfuron Trade name: Sandea®, other	asparagus, pumpkins, cucumbers, cantaloupes, honeydews, crenshaw melons, watermelons, winter squash, dry beans, succulent snapbeans, tomatoes, sweet corn and other vegetables	Cocklebur, common/ giant ragweed, galinsoga, hemp sesbania, kyllinga spp., ladsythumb/ smartweed, prickly sida, redroot pigweed, sunflower, velvetleaf, Venice mallow, wild radish, wild mustard and yellow/ purple nutsedge.	Provides selective post-emergence systemic control. Pre-emergence control may be less consistent.	½ to 1 1/3 oz/acre, depending on crop Add 0.25% v/v nonionic surfactant
BentazonTrade name: Basagran®, other	dry/succulent beans, dry/succulent peas, peanuts, corn, spearmint, peppermint and sorghum	Cocklebur, common purslane, eclipta, hairy nightshade, hemp sesbania, jimsonweed, ladysthumb/ smartweed, mayweed, morningglory, velvetleaf, Venice mallow, wild sunflower and yellow nutsedge.	Provides selective post-emergene contact control. Bentazon has no soil residual activity	1 to 2 pints/acre or 0.375 to 0.75 floz/1000 sqft Spot spray: 0.75 floz per 1 to 2 gallons of water Add 1% v/v crop oil concentrate
Organic Burndown				
Clove oil - active ingredient: eugenol Trade name: Matratec™, other	All fruit, nut and vegetable crops.	Many weeds, nonselective herbicide	Herbicide for organic production that provides non-selective post-emergence contact desiccation of several broadleaf and grass weeds. Post-directed (avoiding spray	5 to 8% solution (spot spray): 5% solution- broadleaf and grass weeds 6 inches in height, temperature below 60° F and cloudy 8% solution - grasses >6 inches in height, temperature below

			on foliage or green bark of crops) and pre-plant applications. Clove oil has no soil residual activity.	60° F and cloudy A non-synthetic adjuvant approved for certified organic crops may be added for improved performance.
Vinegar - active ingredient: acetic acid	All vegetable crops.	Certain broadleaf weeds with grass suppression	Organic post-directed (avoiding spray on foliage or green bark of crops) contact control. Vinegar has no soil residual activity.	At least a 20% solution for the most consistent performance. Multiple applications are often needed for long-term control.
Boiling water (~212°F)	All vegetable crops.	Many weeds	Organic post-directed (avoiding contacting foliage or green bark of crops).	Pour until plant foliage becomes wilted. Multiple applications are often needed for long-term control.

Source: The University of Tennessee, Institute of Agriculture.
**** Organic weed control products listed here can cause human harm such as chemical or heat related burns, if used improperly.***

3.3 Integration of Crop Competitiveness with Herbicides

Integration of Crop Competitiveness like, cultivation of Gautam as high yielding variety, and Prabhat as a weed minimizer variety of rice and adding herbicides like, butachlor @ 1.5 kg/ha at pre-emergence +2,4-D @ 0.5 kg/ha at post emergence found more yield as compare to others (Singh *et al*., 2004). Interaction of bidirectional row orientation in wheat, sowing with 120 kg/ha seeds with 15 cm or 20 cm row spacing and adding isoproturon @ 0.75 kg/ha found better minimization of weeds and provide higher yield of wheat (Angiras and Sharma, 1993).

3.4 Integration of Herbicides with Mulching

Herbicides are used for controlling weeds from the field but they do not effectively control the weeds. The use of crop residues as mulch in the time of weed emergence but only much can not control the weeds of the field. Therefore integrated use of herbicides and much could provide effective control of weeds. The integrated use of herbicide and much also increase the yield of the crop and control the weeds in dry-seeded rice. Mulch is a protective covering of material maintained on the soil surface. Mulching has a smothering effect on weed control by excluding light from the photosynthetic portions of a plant and thus inhibiting the top growth. It is very effective against annual weeds and some perennial weeds like Cynodon dactylon. Mulching is done with dry or green crop residues, plastic sheets, or polythene film. To be effective the mulch should be thick enough to prevent light transmission and eliminate photosynthesis. Paddy straw mulch @ 6 t/ha and adding herbicides like clodinafob and metribuzin @ 195g/ha at the time of post-emergence found the highest yield in the tuber of potato and effective weed control (Shafiq and Kaur, 2021). In the cropping system of rice/wheat, the placement of rice residues as mulching at 6 and 7 t/ha and adding post-emergence herbicides like clodinafop 60 g/ha, sulfosulfuron 25 g/ha, and mesosulfuron+iodosulfuron 14.4 g/ha found more effective to control weeds like *P. minor* and also board leaf weeds (Brar and Walia, 2008). Application of metribuzin or atrazine @ 1.0 kg/ha at the time of pre-emergence and mulching into Intra row trash at 3.5 t/ha, 60 days after planting found effective weeds control on the field of sugarcane (Singh *et al*., 2001). The economic cost of mulching is found more in the high-value horticultural crops. The use of black or white polyethylene sheets for mulching in ber, and adding one hand weeding at 70 days after sowing of bed nursery of ber found more effective weed control against *Cyperus rotundu.* In the ber orchard, application of glyphosate at 0.75, 1.0, and 1.5% found a reduction of *C. rotundus* from the ber orchard respectively 77, 85, and 95% (Yadav *et al*., 1996).

3.5 Integration of Zero Tillage with Herbicides

Zero tillage is generally done in wheat crops and also in maize crops to minimize of cost of cultivation. In zero tillage seeds are sown on standing stubbles of rice. *P. minor* is a major weed of wheat it uptakes the nutrient from the field which was

provided for the wheat (Brar and Walia, 2007a). Sulfosulfuron+metsulfuron 15+4 g/ha, sulfosulfuron+triasulfuron 15+30 and 15+40 g/ha, and metsulfuron+triasulfuron 3+30 g/ha proved better against all weeds under zero tillage (Malik *et al*., 2007). Zero tillage (ZT) as part of a Conservation Agriculture based Sustainable intensification (CASI) package has been one strongly researched and promoted a set of practices to achieve sustainable agricultural intensification. Conservation Agriculture based Sustainable intensification focuses on changed tillage management practices for controlling weeds with zero tillage, crop residue, crop diversification, and use of herbicides (Brown et al., 2018).

3.6 Integration of Hand Weeding with Herbicides

Hand-weeding is a practice of controlling weeding on small farms because it is time-consuming, expensive, and required more labour. Hand weeding is the oldest method for controlling weeds by using an implement known as Khurpi. Hand weeding is more effective for controlling pollution in the field, water, and also in the air requires less herbicide to control the weeds. (Nagar *et al*., 2009) have proved that the integration of herbicides with hand weeding is the most effective and economical method of weed management. In vegetable crops application of pendimethalin 3.3 l/ha or Fluchloralin at 2 lit/ha or metolachlor 2 l/ha as pre-emergence herbicide with one hand weeding 30 days after transplanting was found to best control weeds.

TABLE 8
APPLICATION OF HERBICIDES AS PRE-EMERGENCE WITH ONE HAND WEEDING FOUND BETTER CONTROL OF WEEDS ON MAJOR CROPS

S.N.	Crops	Herbicides	One hand weeding (days after sowing)
1	Rice	Butachlor 2.5 l/ha or Thiobencarb 2.5 l/ha or Fluchoralin 2 l/ha or Pendimethalin 3 l/ha or Anilofos 1.25 l/ha as pre-emergence application.	30-35
2	Wet seeded rice	Pretilachlor + safener at 0.6 l/ha as Pre-emergence application.	40
3	Sorghum	Atrazine 50% WP 500 g/ha as Pre-emergence application.	30-35
4	Cumbu	Atrazine 50 WP 500 g/ha on 3rd day of sowing.	30-35
5	Maize	Atrazine 50 at 500 g/ha (900 lit of water) as Pre-emergence application.	40-45
6	Wheat	Isoproturon 800 g/ha as pre-emergence application.	35
7	Redgram, Blackgram, Greengram, Cowpea &Bengalgram	Fluchloralin 1.5 l/ha or Pendimethalin 2 l/ha 3 days after sowing mixed with 900 l of water.	30-35
8	Soyabean	Pendimethalin 3.3 l/ha	30
9	Groundnut	Fluchloralin at 2.0 l/ha	35-40
10	Cotton	Fluchloralin 2.2 l/ha or Pendimethalin 3.3 l/ha	35-40
11	Rice fallow cotton	Fluchloralin 2.2 l/ha or Pendimethalin 3.3 l/ha	40-45

IV. CONCLUSIONS

Weeds are creating a big problem for growing crops, they reduce production and caused huge economic yield loss of crops. So therefore management of weeds is important for increasing the production of crops and their value. Integrated weed management (IWM) is the best way to control weeds and it's also eco-friendly. Cultural, agronomical, mechanical, chemical, and biological is the methods that are used for controlling weeds. Mainly herbicides are used for controlling weeds but herbicides are very harmful to both humans and plants. The biological method is the best way to control weeds from the field and it's also nonharmful for humans, animals, and plants. Tillage and puddling are used for the removal of weeds seeds from the infested field. Mulching is knowns as leaving of crop residues or plastic for controlling weeds infestation in the crops fields. In Nepal and India mostly herbicides are used for controlling weeds because other practices are more costly as compared to herbicides. Biological weeds control methods are generally used in organic farming to find organic food from the crops field. Using herbicides to control weeds creates a big problem for a growing population. Herbicides are not good for human and plant health so other practices like cultural, mechanical, agronomical, and biological methods are used for the control of weeds are best for human and plant health. cultural, mechanical, agronomical, and biological methods for controlling weeds are also ecofriendly and give the best performance to control the weeds from the fields.

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