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Herbicidal Weed Management in Soybean (*Glycine Max* (L.) Merril)

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ABSTRACT

Weed management is essential for any current system of agricultural production, especially for large monoculture areas, which exert high pressure on the environment. Soybean is among the largest monoculture registered worldwide, with 102 million hectares harvested only in 2010. The leading countries of production are Argentina, Brazil and the United States, with more than 70% of the total cultivated area. Along with China and India, these five countries represent 90% of all produced soybean. The production incentive is related to growing global demand for oil and protein for food and feed, as well as the feasibility of crops for biodiesel production, extremely important for the global economy. Meanwhile, weeds are considered the number one problem in all major soybean producing countries. Even with advanced technologies, producers note high losses due to interference by weeds. According to estimates, weeds, alone, cause an average reduction of 37% on soybean yield, while other fungal diseases and agricultural pests account for 22% of losses.

KEYWORDS: *herbicidal, weed, management, soybean, Glycine Max (L.) Merril, crop, rotation, cultivars*

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INTRODUCTION

In the United States, it is considered that weeds cause losses of several millions of US dollars annually. In Brazil, with an average production of 75 million tons, it is estimated that expenses on weed control represent between 3% and 5% of total production cost, which means more than US$ 1.2 billion used in that country, only for weed chemical control in soybeans. Disregarding the high cost, weed might be controlled in soybean crop using good management practices of all available methods, combining them in an herbicidal weed management[1,2]. Crop rotation is a rather efficient method, since it allows an easy control of the most troublesome weeds. In order to achieve success on crop rotation, weeds must be managed throughout the growing soybean season. Using full capacity of crop competition is another alternative, yet this tool is often overlooked. Despite differences between soybean cultivars used worldwide and the main weed species which attack these cultivars, there are many resemblances in management practices and control. The species hairy fleabane, *Conyza bonariensis* (L.) Cronq., horseweed, *Conyza canadensis* (L.) Cronq., goosegrass, *Eleusine indica* (L.) Gaertn., barnyardgrass, *Echinochloa crus-galli* (L.) Beauv., johnsongrass, *Sorghum halepense* (L.) Pers., beggarticks, *Bidens pilosa* L. and common ragweed, *Ambrosia artemisiifolia* L., are common weeds in Argentine, Brazilian and American soybean crops.[3,4] The burndown and subsequent post-emergence (POST) spraying of crop with glyphosate usually occur from south to north in the American continent, with some distinctions among products used in mixture with glyphosate for managing resistant weeds. All these factors increase the selection pressure even more. The introduction of GR (glyphosate-resistant) soybean, genetically modified (GM), contributed to standardization of weed management. With a large adoption of this technology, there are many concerns regarding the control and the high selection pressure on common weed species in soybean. In the US, more than 93% of soybean has the GR technology. In Brazil and Argentina, these values represent 80% and 99%, respectively.[5,6]

The use of very similar technologies as well as the facility of proliferation of weeds has intensified

reported herbicide resistance. Since the first report of *E. indica* resistance, in Malasia (1997), 22 species (biotypes) are already not controlled by glyphosate and 10 show multiple resistance. The number of reports increases every year and, in 2011, 7 weed resistance cases were recorded. The evolution of weed resistance to glyphosate also worries members of the Weed Science Society of America, mainly by the spread rate and by the impact on ecosystems. New technologies derived from genetic alteration of cultivars resistant to herbicides are part of management alternatives to glyphosate. Many of them still under test should be available on short notice.[7,8] In Brazil, both soybean resistant to ALS (acetolactate synthase) inhibitors and those resistant to 2,4-D should take up areas with a history of weed glyphosate resistance. In the US, besides soybean resistant to dicamba and that resistant to glyphosate + ALS, mixtures are used on crop pre-emergence (PRE), for example, dimethenamid and saflufenacil (new active ingredient). Spraying of encapsulated ingredients (acetochlor) at soybean POST and at weed PRE also come up as management alternatives. Despite efforts on weed control in soybeans, the benefits of IWM based on preventive and cultural controls will always be fundamental to the maintenance of monocultures. However, it appears that much of what is discussed about herbicidal weed management is slightly practical, with corrective measures mostly. This chapter aims to present some focal issues related to weed management in soybean growing areas, which include weed potential to cause severe damages and yield losses by weeds, the evolution of resistant weeds in GR soybean monoculture, the soybean management characterization in the main producing countries and discussions about the benefits of herbicidal use as an accurate control measure. It presents a set of information for researchers and experts on weed management service area, reporting clear and objectively the major impacts of the current management used and the outlook for soybean farming.[9,10]

Weed Free Soybean

First 6 to 7 weeks after seeding is the critical period for crop weed completion. Clean cultivation is, therefore, essential during the critical period.

Cultural Management: Since soybean is sown in rows, bullock drawn harrows can be used for controlling the weeds. Two intercultivations, first at 20-30 DAS and the second around 45 DAS along with manual weeding can maintain the soybean field weed free for economic yield

Use of Herbicides: A wide range of soil and foliage applied herbicides provides moderate to excellent of wide range of weeds infesting soybean crop.

PRE herbicides	PPI herbicides
Fluchloralin (1.0-1.5)	Alachlor (1.5-2.0)
Acetochlor (1.0-1.5)	Clomazone (0.75-1.5)
Vernolate (1.5-2.5)	Metribuzin (1.0-1.5)
Trifluralin (0.75-1.0)	Chlorimuron ethyl (0.004-0.008)
	Metolachlor (1.0-1.5)
	Trifluralin (1.5-2 .0)
	Lactofen (1.0-1.5)
	Oxyfluorfen (1.0-1.5)
	Imazethapyr (0.10-0.50)
	Imazethapyr (50-60g)

Combination of Trifuralin and alachlor or Triallate (1.0-1.5) applied PPI is the best for season long weed control. PRE combination of Pendimethalin (0.5 - 0.75) and Imazethapyr (50-75g) is also equally effective for weed free environment.

Discussion

Effective weed management in soybean (*Glycine max* L.) cultivation is essential to protect soybean growth and yield from weed competition during the growing seasons. Soybean is vulnerable to weed interference because the seeds are sown with wide spacing to develop branches and to allow the canopy to expand fully during the late growth stage .The late canopy closure allows weeds to be established more easily in soybean than in other crops .To effectively manage weed infestations in soybean, various weed management methods, including herbicide application, tillage practices, and crop rotation, are used in combination. The weed control methods can be modified based on the field conditions. However, herbicide use has generally been incorporated into weed management practices regardless of region. The Far Eastern region of Russia is the major agricultural area (approximately 5 million ha) in which soybean, maize, and wheat are traditionally cultivated for food and feedstock [8]. In most of the Far Eastern region, including Amur Oblast, Khabarovsk krai, and Primorsky krai, early-maturing soybean has been mainly cultivated for the production of soybean oil. A

difficulty in soybean cultivation is in the management of troublesome weeds. On average, the grain yield of soybean in Primorsky krai was approximately 1.1 t ha−1 , which is lower than 1.5 t ha−1 yield of the Russian Federation. Such a low soybean yield was attributed to poor weed management practices, which allowed the weeds to cause a severe yield loss of soybean. In the Far Eastern region of Russia, conventional weed management practices have focused on weed control by a single application of post-emergence herbicide, bentazon + acifluorfen. *Ambrosia artemisiifolia* L. (common ragweed), *Chenopodium album* L. (common lambsquarters), *Sonchus oleraceus* L. (annual sowthistle), *Echinochloa crus-galli* L. (barnyardgrass), and *Beckmannia syzigachne* Steud. (American sloughgrass) were reported to be the dominant weeds in soybean fields located in the region. In particular, common ragweed was inconsistently controlled when single post-emergence herbicides were applied. [11,12] To achieve a greater soybean yield and better economic return from herbicide use for weed control, herbicide use should be systematically investigated to establish an herbicide-based weed management system for soybean in the Far Eastern region of Russia. Previous studies indicated that the sequential applications of pre-emergence (PRE) and post-emergence (POST) herbicides provided greater soybean yield than sole herbicide applications. However, no study has yet established an herbicide-based weed management system that can be effective and economical for soybean production in the region. Therefore, this study was aimed at establishing an effective and economic weed management system based on the sequential applications of PRE and POST herbicides for soybean production in the Far Eastern region of Russia. A field experiment was conducted to evaluate the performance of the PRE and POST herbicides in weed control and soybean safety. A large field experiment was also conducted to evaluate the performance of the sequential application of PRE and POST herbicides in weed control, soybean yield and economic return.[13]

In general, the weed control efficacies varied among the herbicide combinations and their application timings. The variations in weed control efficacies have been mainly attributed to the weed composition and size the relative rate of weed growth and their susceptibility to herbicides at the time of spraying under field conditions. Previous studies suggested that various herbicides should be sequentially used for soybean to make it superior to weeds. The timely sequential application of PRE and POST herbicides is effective to control the major troublesome weed species, an annual broadleaf weed, common ragweed, and an annual grass weed, barnyardgrass. In particular, common ragweed and barnyardgrass are commonly found in soybeans across Primorsky krai, causing soybean yield losses of 20% compared to weed-free plots [14,15]. Our results also demonstrated that sequential application can be more effective in weed management for soybean production than any sole application of herbicides in Primorsky krai, Russia. Among the sequential treatments, the acetochlor-based sequential application provided the best performance for weed control efficacy and soybean yield protection in the soybean fields of Bogatyrka. Acetochlor was proven to be highly effective against both broadleaf and grass weeds when applied immediately after sowing the soybean. For those weeds that escaped and are established after the PRE application of acetochlor, POST herbicides can be an effective management tool. Acetochlor-based sequential applications with various POST herbicides provided a season-long weed control. [16,17] In our results, the acetochlor-based sequential application achieved the greatest soybean yields of approximately 1.7 t and 1.9 t ha−1 in 2012 and 2013, respectively. The economic return of the acetochlor-based sequential application provided with 724.5 US$ and 1155.6 US$ ha−1 of economic returns in 2012 and 2013, respectively (Figure 4; Tables S1 and S2). However, the use of acetochlor (PRE), acifluorfen (POST), and tepraloxydim (POST) has recently been banned in the European Union due to its potential risk to human health and the environment. As an alternative of acetochlor, S-metolachlor can be considered. The sequential application of S-metolachlor (PRE) followed by bentazon + imazamox (POST) at 30 DAS in 2013, showed relatively high soybean yield, giving approximately 1.2 t ha−1 of soybean yield, similar to those of the acetochlor-based sequential application. The economic return of the S-metolachlor-based sequential application was 694.0 US$ in 2013. In addition, our new test with the other potential PRE herbicides conducted in 2014 revealed that clomazone could replace acetochlor for the sequential herbicide application. As an alternative of acetochlor, prometryn could be considered, but has also been banned in the European Union. The PRE application of clomazone was more effective in major weed control than the PRE herbicide acetochlor and prometryn (data not shown), providing better advantages in soybean yield (Figure S5). The sequential application of clomazone (PRE) followed by bentazon + imazamox (POST) can replace the acetochlor-based sequential application for soybean production across Primorsky krai, Russia. Although the sequential application of PRE and POST

herbicides is more expensive than solo application of either PRE or POST herbicide, our results clearly demonstrated that the sequential herbicide application can protect soybean yield significantly from weed competition, resulting in a dramatic increase in economic return. Further work is necessary to investigate the effectiveness of the sequential application of PRE and POST herbicides for weed management for soybean production in other regions of Russia.[15,16]

Results

Several new herbicides have been registered for weed control in soybean. These new herbicides do not have an active ingredient with a new mode of action, but they are tank-mixtures of existing herbicides. A season-long weed management plan should include herbicides with Multiple Modes of Action. (For more information see the newly revised industry Herbicide Classification chart.)Following are new soybean herbicides that should be available for the 2017 growing season. Authority®Elite [sulfentrazone (7.55%) + *S*-metolachlor (68.25%)]. It is a soil-applied herbicide for control of broadleaf, grass, and sedge weeds in soybean. The crop rotation restriction for corn and sorghum is 10 months. It should not be applied at a rate of more than 38.7 fl oz/acre per year. EPA Reg. No. 279-3442. BroadAxe XC has similar herbicide active ingredients as Authority Elite. EPA Reg. No. 279-3442-100. Modes of Acton: 14 + 15.Authority®Maxx [sulfentrazone (62.12%) + clorimuron-ethyl (3.88%)]. It can be applied pre-plant or pre-emergence in soybean for broadleaf and partial grass weed control. The application rate is 6 to 9 oz/acre depending on soil texture and organic matter content. EPA Reg. No. 279-9560. Modes of Acton: 14 + 2.

Rowel FX applied pre-emergence at 3 oz/acre followed by XtendiMax applied post-emergence at 22 fl oz/acre in Roundup Ready 2 Xtend soybean at the South Central Ag Lab near Clay Center.

Enlist™ Duo [2,4-D choline (24.4%) + glyphosate (22.1%)]. Enlist Duo can be applied only in Enlist corn and in Enlist soybean for control of annual and perennial weeds. Do NOT apply this product in Roundup Ready or Liberty Link soybean. This herbicide is based on Colex-D technology. Products with 2,4-D that do not contain Colex-D technology are not authorized for use in conjunction with Enlist corn and soybeans. It is a systemic herbicide intended for control of annual and perennial weeds. Apply 3.5 to 4.75 pints of Enlist Duo per acre. Make one to two applications with a minimum of 12 days between applications. In Enlist Soybean, apply 3.5 to 4.75 pints of Enlist Duo per acre. Apply when weeds are small and any time after soybean emergence but no later than R2 (full flowering stage). Do not apply more than 4.75 pints of Enlist Duo per acre per application. Do not apply more than 14.25 pints/acre of Enlist Duo per season. EPA Reg. No. 62719-649. Modes of Action: 4 + 9.[17]

Fierce® XLT [flumioxazin (24.57%) + pyroxasulfone (31.17%) + chlorimuron (6.67%)]. Fierce XLT in Nebraska can only be used in the fields south of Route 30 and east of US Highway 281. This herbicide provides residual control of broadleaf and grass weeds in soybean. It also provides additional burndown activity when used as part of a burndown program. Moisture is necessary to activate this herbicide in soil for residual weed control. Do not apply more than 5.25 oz/acre per growing season. Do not apply additional chlorimuron-containing herbicides to fields treated with Fierce XLT. EPA Reg. No. 59639-194. Modes of Acton: 14 + 15 + 2.

Marvel™ [fluthiacet-methyl (1.2%) + fomesafen (30.08%)]. This is a new premix herbicide from FMC for post-emergence weed control in soybean. It can be applied at 5 to 7.25 fl oz/acre from pre-plant through full flowering stage (prior to R3). It is a contact herbicide; therefore, good coverage is essential for optimum weed control. Do not apply more than 7.25 fl oz/acre per application and 9.75 fl oz/acre per year. EPA Reg. No. 279-3455. Modes of Acton: 14 + 14.

Presidual™ [*S*-metolachlor (58.2%) + metribuzin (13.8%)]. Presidul is for control of certain grasses and broadleaf weeds in soybean. The application rate of this herbicide is 2.0 to 2.9 pt/acre depending on soil texture and organic matter content. EPA Reg. No. 1001162-1381. Modes of Acton: 15 + 6.

Warrant® Ultra [acetochlor (30.2%) + fomesafen (7.1%)]. In Nebraska Warrant Ultra can be applied only in counties east of or intersected by US Highway 281. It can be applied as a preplant surface, pre-emergence, or post-emergence treatment in soybean. A maximum of 48 fl oz/acre of this herbicide can be applied in alternate years in soybean fields in these Nebraska counties. It can provide residual as well as

burndown activity. This herbicide can be applied only once per growing season. EPA Reg. No. 524-620. Modes of Acton: 15 + 14.

XtendiMax™ [dicamba (42.8%)]. XtendiMax is a new dicamba product to be used on dicamba-tolerant (Roundup Ready 2 Xtend) soybean. The formulation contains Vapor Grip, which reduces the volatility of this product. This product has 2.9 lb/gallon of DGA salt of dicamba in liquid, so 22 fl oz provides 0.5 lb of dicamba, which is equivalent to 16 oz of Clarity and other 4 lb/gallon dicamba products. The minimum application rate for any use is 22 fl oz/ac. The maximum rate per application prior to soybean emergence is 44 fl oz/acre, which is also the total maximum allowed for all applications prior to soybean emergence. The maximum rate per application after soybean emergence is 22 fl oz/acre. The total of all POST applications cannot exceed 44 fl oz/acre. The cumulative application rate per year cannot exceed 88 fl oz/ac. Use of ammonium sulfate, UAN, etc. is not allowed due to their potential to increase the volatility of dicamba. Certain adjuvants can be mixed with XtendiMax and are listed at xtendimaxapplicationrequirements.com. Post-emergence application of XtendiMax can be made from emergence up to and including the R1 stage of soybean growth. Weeds should be less than 4 inches tall at time of post-emergence application. EPA Reg. No. 524-617. Mode of Acton: 4.

Zidua® PRO [imazethapyr (13.45%) + pyroxasulfone (23.06%) + saflufenacil (4.81%)]. Zidua PRO is a premix of Pursuit, Zidua, and Sharpen. It provides contact burndown and residual pre-emergence control of annual grass and broadleaf weeds in soybean. It can be applied from 4.5 to 6.0 fl oz/acre depending on tillage system. It has three modes of action and will be a good herbicide to consider in a resistant weed management program. EPA Reg. No. 7969-365. Modes of Action: 2 + 15 + 14.[18,19]

Conclusions

We have received some calls inquiring about post herbicide options for soybeans. If the field did not receive a burndown herbicide or a residual applied near planting, weeds like dandelion, resistant marestail/horseweed, etc. will be very difficult to control postemergence in soybean. Also, many of the typical soil applied residual soybean herbicides (e.g., Valor, Authority, Sharpen, metribuzin, etc.) cannot be applied over the top of soybeans because of injury concerns. Below is a list of herbicides that have primarily foliar broadleaf activity and/or residual activity and are allowed post along with their labeled application timings and strengths. Unfortunately, most of these herbicides will not handle dandelion, burdock, curly dock, etc. very well. Keep in mind that products such as Dual Magnum, Outlook, Warrant, and Zidua will not control emerged weed, but they can provide residual activity of certain annual weeds, so they will need to be tank-mixed with herbicides that have foliar activity. Additional details about these herbicides can be found in Table 4-14 of the Mid-Atlantic Field Crop Weed Management Guide. Below are brief descriptions of selected herbicides that can be applied post in soybean; keep in mind this is not a comprehensive list.

- Anthem Maxx – can be applied post up to 3rd trifoliate but at least 60 days before harvest. Since it contains Cadet some annual broadleaves (not marestail) will be controlled by foliar contact but it tends to be weak on perennials. The pyroxasulfone (Zidua) portion will not control existing weeds but will provide residual activity on annual grasses and small seeded broadleaves.
- Basagran – after emergence up to 30 days before harvest (general control of small annual broadleaves – good on cocklebur, lambsquaters, smartweed, and velvetleaf).
- Cadet – Preplant through full flowering (general control of small annual broadleaves – excellent on velvetleaf, fair on others).
- Classic (or Synchrony) – after 1st trifoliate leaf up to 60 days before maturity (general control of small annual broadleaves – good on cocklebur, jimsonweed, pigweeds, and smartweed).
- Cobra – apply post up to 45 days before harvest-1 to 2 trifoliate leaves is typical (general control of small annual broadleaves – good on jimsonweed, nightshade, pigweeds, ragweeds, and smartweed).
- Dicamba products (Engenia, Xtendamax/FeXapan) – for use in Xtend soybean varieties only; Applications can be made from soybean emergence through R1 (flowering) or 45 days after planting (whichever comes first). Controls many annual and perennial broadleaf weeds.
- Dual Magnum – can be applied post but the exact application timing is not specified but at least 90 days before harvest. It will not control existing weeds but will provide residual activity on annual grasses and small seeded broadleaves and nutsedge.
- Enlist One and Enlist Duo – for use in Enlist E3 soybean varieties only; Applications can be made from soybean emergence through R2 growth stage (full flower). Controls many annual and

perennial broadleaf weeds. Enlist Duo contains glyphosate thus grassy weeds will be controlled as well.

- FirstRate – 1st soybean trifoliate through R2 (full flower) and 70 days before harvest (general control of small annual broadleaves – good on cocklebur, ragweeds, and velvetleaf).
- Glyphosate (Roundup Ready only) - emergence through full flowering. Overall good weed control of many species but it can be weak on perennials such as dandelion and glyphosate-resistant weeds such as marestail.
- Harmony SG – after 1st trifoliate has expanded fully and no later than 60 days before harvest (general control of small annual broadleaves – good on lambsquaters, pigweeds, smartweed, and velvetleaf).
- Liberty (varieties containing Liberty Link trait) – emergence up to R1 (bloom stage). Broadspectrum control of many small annual weeds (including marestail, Palmer amaranth, waterhemp) but tends to be weak on many perennials.
- Outlook – can be applied post from soybean cracking to 5th trifoliate. It will not control existing weeds but will provide residual activity on annual grasses and small seeded broadleaves.
- Pursuit – pre to before bloom and 85 days before harvest (general control of small annual broadleaves and some grasses – good on cocklebur, pigweeds, smartweed, and velvetleaf).
- Python - pre and from 1st to 5th trifoliate (generally will not control emerged weeds, but provide residual control of annual broadleaves).
- Raptor – early post and before bloom (general control of small annual broadleaves and some grasses – good on cocklebur, lambsquaters, pigweeds, and velvetleaf).
- Reflex or Flexstar (or Flexstar GT with glyphosate) – pre to bloom and prior to 45 days of harvest (Prefix also has an early post label) (general control of small annual broadleaves – good on jimsonweed, pigweeds including Palmer and waterhemp, ragweeds, smartweed, and velvetleaf).
- Ultra Blazer - soybeans should have at least 1 trifoliate leaf and 50 days before harvest (general control of small annual broadleaves – good on jimsonweed, pigweeds, nightshade, common ragweed, and smartweed).
- Warrant – emergence to R2; but label recommends application at V2-V3 state (will not control emerged weeds but provides residual control of annual grasses and some broadleaves). Warrant Ultra contains fomesafen (Reflex) and is designed to be applied post (emergence to R2 stage).
- Zidua SC – can be applied post from soybean cracking to 6th trifoliate. It will not control existing weeds but will provide residual activity on annual grasses and small seeded broadleaves.
- Post grass herbicides – Assure II, Fusilade DX, Fusion, Poast, Select/clethodim control many annual and perennial weedy grasses and volunteer corn in soybean. See label for specific application details.[19]

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