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Short title: Weed Management in Brazil

Assessment of crop and weed management strategies prior to introduction of auxin-resistant crops in Brazil

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A stakeholder survey was conducted from April through June of 2018 to understand stakeholders perceptions and challenges about cropping systems and weed management in Brazil. The dominant crops managed by survey respondents were soybean (73%) and corn (66%). Approximately 75% of survey respondents have grown or managed annual cropping systems with two to three crops cultivated per year in succession.

Eighteen percent of respondents manage only irrigated cropping systems, and over 60% of respondents adopt no-till as a standard practice. According to respondents, the top five troublesome weed species in Brazilian cropping systems are horseweed (asthmaweed, Canadian horseweed and tall fleabane), sourgrass, morningglory, goosegrass, and dayflower (Asiatic dayflower and Benghal dayflower). Among the nine species documented to have evolved resistance to glyphosate in Brazil, horseweed and sourgrass were reported as the most concerning weeds. Other than glyphosate, 31 and 78% of respondents manage acetyl-CoA carboxylase (ACCase)-inhibitor and/or acetolactate synthase (ALS)-inhibitor resistant weeds, respectively. Besides herbicides, 45% of respondents use mechanical, and 75% use cultural (e.g., no-till, crop rotation/succession) weed control strategies. Sixty-one percent of survey respondents adopt cover crops to some extent to suppress weeds and improve soil chemical and physical properties. Nearly 60% of survey respondents intend to adopt the dicamba or 2,4-D resistant crops when available. Results may help practitioners, academics, industry and policy makers better understand the bad and the good of current cropping systems and weed management practices adopted in Brazil, and adjust research, education, technologies priorities and needs moving forward.

Nomenclature: 2,4-D; dicamba; glyphosate; Asiatic dayflower, *Commelina communis* L.; asthmaweed, *Conyza bonariensis* L. Cronquist; Benghal dayflower, *Commelina benghalensis* L.; Canadian horseweed, *Conyza canadensis* L. Cronquist; dayflower, *Commelina* spp; horseweed, *Conyza* spp.; sourgrass, *Digitaria insularis* L. Mez ex Ekman; morningglory, *Ipomoea* spp.; goosegrass, *Eleusine indica* L. Gaertn.; tall fleabane, *Conyza sumatrensis* Retz. E. Walker; corn, *Zea mays* L.; soybean, *Glycine max* L. Merril

Key Words: Cover crops; herbicide weed resistance; no-till; survey; weed control

Introduction

Agriculture has undergone major evolution in the past century leading to a significant increase in crop yields (Warren 1998). From 1930s to 2010s, grain corn, cotton (*Gossypium hirsutum L.*), rice (*Oryza sativa L.*), and soybean have experienced a crop yield increase in the United States (US) of 740%, 390%, 350% and 290%, respectively (USDA-NASS 2020; Warren 1998). The discovery of synthetic herbicides, including MCPA, and 2,4-D in the 1940s had a positive impact on crop yields by allowing more effective control of weeds (Troyer 2001). For example, 2,4-D was adopted as an effective (>90%) broadleaf weed control compound used at lower concentrations compared to organic herbicides, such as sodium chlorate and sodium thiocyanate (Marth and Mitchell 1944). The introduction of *S*-triazine (e.g., atrazine) herbicides in the 1950s represents another milestone in terms of weed control and herbicide popularity amongst growers (McFarland and Burnside 2011). The combination of PRE and POST herbicides plus cultural and mechanical methods reduced the need for labor-intensive hand weeding, increased efficacy and greatly reduced the costs for weed management (Gianessi and Reigner 2007; Holstun et al. 1960)

From the 1940s to the 1980s (herbicide discovery era), novel herbicide chemistries with broad weed control spectra, application window in relation to crop developmental stage, and selectivity were discovered. During that time, on average, a new herbicide site of action (SOA) was introduced every two years (Appleby 2005; Duke and Dayan 2018). Herbicides quickly became synonymous of weed management and through this date represent the most commonly adopted tool for weed control in conventional production systems. In recent years, given the shortage and challenges related to novel herbicide discovery (Duke 2012), industry focus has shifted towards

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biotechnology and the development of crop hybrids or varieties genetically engineered with herbicide-resistant (HR) genes (Bonny 2011; Owen 2000). In 1996, glyphosate-resistant (GR) soybean (Roundup Ready®) was the first transgenic HR crop to be introduced, followed by GR-corn and GR-cotton, which allowed growers to spray glyphosate, a systemic, non-selective and very effective herbicide POST in GR-crops (Padgette et al. 1995). Glyphosate use has risen followed the introduction of GR crops in 1996 (Benbrook 2016). This increase was further accelerated with introduction of GR crops in developing countries such as Brazil and Argentina in the early 2000s. In 2014, glyphosate represented 66% of herbicide applications in Brazil (SIDRA-IBGE 2020). GR crops are documented as the most adopted technology of modern agriculture (Green 2018). However, glyphosate overreliance resulted in weed shifts and evolution of GR-weeds (Owen 2008). Thus far, there are 50 confirmed GR weed species worldwide, 9 weed species in Brazil, including sourgrass and horseweed (Heap 2020).

Rapid evolution of GR weeds prompted the development of other HR crops such as glufosinate, 2,4-D, and dicamba-resistant (DR) soybean, cotton and/or corn. The new synthetic auxin-resistance (AR) technology was introduced in 2017 to the US and is soon expected to become available in Brazil. The Roundup Ready 2 Xtend® (Bayer Crop Science, St. Louis, MO) allows the use of glyphosate and new dicamba formulations, including diglycolamine salt with VaporGrip®, an acetic acid-acetate buffering system, or a dicamba salt N,N-Bis-3-aminopropyl methylamine in DR-crops. Moreover, the 2,4-D resistant technology marketed as Enlist E3® (Corteva Agriscience, Wilmington, DE), which allows glyphosate, glufosinate, and a new 2,4-D-choline salt formulation application in Enlist® crops (Wright et al. 2010). These new 2,4-D and dicamba formulations are products with reduced volatility compared to their previous

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formulations. However, in the first year of AR crops in the US, it was estimated near 1.4 million ha with dicamba injury on non-DR soybeans (Oseland et al. 2020). In Nebraska, 51% of survey respondents noted dicamba injury in their non-DR soybeans in 2017 (Werle et al. 2018). It is still controversial whether the injury on sensitive vegetation is due to dicamba vapor, particle drift, and/or tank contamination. Nonetheless, the upcoming introduction of AR-crops in Brazil raises concerns of off-target movement (OTM) and requires research.

The introduction of AR crops increases complexity but represents a new milestone in terms of weed management; thus documenting current practices prior their introduction and after nearly 20 years of GR crops use in Brazil is necessary. Surveys are useful tools for documenting agricultural practitioners' knowledge and perceptions regarding specific strategies. For example, a survey with pesticide applicators indicated the need for further education regarding application of synthetic auxin technologies in Missouri, US (Bish and Bradley 2017). Also, a survey conducted in Argentina demonstrated that weed control is based on empiric short term decisions with > 53% using solely herbicides for weed management (Scursoni et al. 2019). A survey documented a concern on protoporphyrinogen oxidase (PPO)–inhibitor resistant Palmer amaranth (*Amaranthus palmeri* S Watson) in southwestern US, the need for diversified weed management strategies, and additional cover crop research in that geography (Schwartz-Lazaro et al. 2018). Therefore, documenting current weed management practices in different regions of Brazil could improve weed management decisions, policy, education, investments, research priorities, and further needs.

In Brazil, growers rely mainly on crop advisors for crop management decisions, including strategies for weed control (dos Reis MR, personal communication). The use

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of survey questionnaires in Brazil with agricultural practitioners has been lacking. Therefore, the objective of this survey was to understand from growers and crop advisors (e.g., crop consultants, coop, industry, and University representatives) current agricultural management practices, perceptions, and challenges regarding current cropping systems and weed management in Brazil. The survey had a specific focus on crop management, troublesome and HR weeds, and evaluating interest, value and potential challenges the new AR technologies may face if deployed/adopted in Brazil.

Material and Methods

A survey was developed to understand Brazilian stakeholders' perceptions and challenges about cropping systems and weed management strategies (Table 1). To reach a broad representation, the survey was conducted online using Qualtrics (Provo, Utah, US) linked to the University of Wisconsin-Madison and circulated via social media, including Twitter®(San Francisco, California, US), Facebook®(Menlo Park, California, US), LinkedIn®(Sunnyvale, California, US), and Whatsapp®(Menlo Park, California, US). The messenger Whatsapp®is popular amongst agricultural stakeholders in Brazil. Extension agents also assisted with distributing the survey questionnaire to stakeholders through their electronic listservs.

The survey comprised three sections. Questions in the first section focused on respondents' demographics: Q1) role (e.g., grower or industry rep), Q2) region, and Q3) managed area (ha). The second section was designed to focus on cropping systems practices: Q4) managed crops, Q5) crop succession, Q6) tillage, Q7) irrigation, Q8) cover crops and Q9) crop-livestock integration. The third section focused on weed management strategies: Q10) troublesome weeds, Q11-14) HR weeds, Q15) herbicide

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programs and SOA, Q16-17) herbicide application information, Q18) non-chemical weed management, and Q19) adoption of AR crops. The third section also incorporated general questions (Q20-21) about cropping systems and weed management challenges (Table 1).

The online survey was available from April 1 through June 30, 2018. Results were exported from Qualtrics as a Microsoft Excel (Microsoft Office, Redmond, WA) file with the answers to each question in separate columns. Survey data were sorted and analyzed using the *sort*, *filter*, and *count* functions in Microsoft Excel and *summarise*, *filter*, and *pipe* in the package tidyverse (Wickham and RStudio 2017) of R statistical software (R Core Team 2020). For most questions, results are presented as: (1) percent of respondents, (2) percent of answers and (3) percent of number of ha represented. Not every respondent answered every question; for some questions, respondents were allowed to select multiple choices (e.g., Q15, herbicide programs and SOA). Moreover, survey respondents were grouped according to their region as listed in the demographic geopolitical Brazilian map: North, Northeast, Midwest, Southeast, and South (Figure 1).

Results and Discussion

Crop Management

Demographics. Survey answers were obtained from 343 stakeholders, representing 21 of 27 Brazilian states. Most survey respondents were located in the South (43%) and Southeast (38%) regions of Brazil; however 43% of managed ha represented in the survey are in the Midwest region (Table 2). The South and Southeast regions encompassed of small/medium farm size (<500 ha), while the Midwest, North and

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Northeast regions represent the newly expanded agricultural region in Brazil, with farm size of >500 ha up to 100,000 ha (Dias et al. 2016). Most survey respondents identified themselves as agronomists (69%), followed by university and industry representatives (22%), growers (21%), and consultants (9%; Table 2). Respondents represent a total of 5,7 million crop ha, a representative area as there are 78 million ha of Brazilian territory occupied with crops and planted forest (IBGE 2020).

Cropping systems. The survey showed that only 16% of respondents manage crops in conventional tillage in Brazil, with highest no-till practice in the Midwest (71%) (Table 3). Six out 10 respondents adopt/recommend cover crops to some extent (Table 3), with oats (*Avena sativa* L., 48%), sunn hemp (*Crotalaria juncea* L., 27%), pearl millet (*Pennisetum glaucum* L. R. Br., 29%), spreading liverseed grass (*Urochloa* spp., 27%), perennial ryegrass (*Lolium perenne* L. ssp. perenne, 22%), and field mustard (*Brassica rapa* L., 16%) ranked as the top cover crop species adopted by respondents (Table 3). Moreover, crop-livestock integration is adopted by 37% of respondents in Brazil (Table 3). Crop-livestock establishment varies within Brazilian regions, plant species selection, and rotation sequence between livestock systems and crop succession/rotation (Moraes et al. 2014).

Survey results show that crop succession (i.e., crop rotation within a year) is a common practice in Brazil, whereas 71% of respondents manage at least two crops in the same land within a year (Table 3). In the South, nearly 40% of respondents grow three crops in the same land within a year but 20% in the Midwest, which strongly rely on two crop succession systems (74%). Soybean is usually planted as the first crop, followed by corn or cotton, and pulse, small grains (barley [*Hordeum vulgare* L.], oats, cereal rye [*Secale cereale* L.] and triticale [*Triticosecale rimpaui* C. Yen & J.L. Yang]) or

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cover crops across the country (Cerdeira et al. 2011). The number of crops per year is likely a result of moisture availability due to higher and more regular precipitation in southern regions than Northern Brazilian states (Alvares et al. 2013). Moreover, 50% and 32% of survey respondents manage rainfed (non-irrigated), and partially irrigated fields, respectively (Table 3). Therefore, according to our survey no-till, crop succession, and cover crops are common practices in Brazil.

No-till strongly contributed for the expansion of annual crops in Brazil, especially in the *Cerrado* (savanna biome) area in the 1980s onwards (Sanders and Bein 1976). The geography of *Cerrado* biome includes the Midwest and parts of the Southeast, North and Northeast region of Brazil (Figure 1). The *Cerrado* is characterized with favorable topography for agriculture but low soil fertility (Goedert 1983), which was mainly used for pastures. In the early 2000s, it was estimated that 11% and 41% of the *Cerrado* area was covered with cropland and planted pastures, respectively (Klink and Machado 2005). The cropland in the *Cerrado* expanded 81% from 2000 to 2014, mainly replacing poorly managed pastures (Zalles et al. 2019). No-till, crop succession, cover crops, and crop-livestock integration strategies have resulted in improved soil chemical and physical properties in Brazil, especially in the *Cerrado* biome (Moraes et al. 2014; Yamada 2005).

The current expansion of cropland is occuring to the new *Cerrado* areas within the states of Maranhão, Tocantins, Piauí, Bahia (MA-TO-PI-BA) and in the Northeast and North parts of the Amazonian biome in the state of Pará (North region) (Lucio et al. 2019; Zalles et al. 2019). The steady increase of cropland in Brazil is partially due to the success of no-till and soybean production in the *Cerrado* (Araújo et al. 2019; Fearnside 2001). The importance of soybean for the Brazilian agriculture is highlighted

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in our survey as it is the most managed crop across the five major regions (Figure 2). Currently, there are 36 million ha of soybean grown with productivity of 119 million tonnes of grain, which makes soybean the top agricultural export commodity of Brazil (Oliveira 2016).

Weed Management

Herbicide programs. The wide adoption of no-till soybean systems in Brazil would be less likely without glyphosate. Because glyphosate is a non-selective and systemic herbicide, it provides high vegetation control (Duke and Powles 2008). Over 80% of respondents spray/manage burndown type herbicides for management of existing vegetation prior to establishment of annual crops (Table 4). High glyphosate reliance is clearly demonstrated as this is the main herbicide used for burndown applications to target weed control and cover crop termination in several annual and perennial cropping systems (Figure 3). The synthetic-auxin (e.g. 2,4-D), photosystem I (PSI)- (e.g., paraquat) and PPO- (e.g., saflufenacil) inhibitor herbicides are additional herbicide options sprayed as part of burndown programs. The survey also showed glyphosate as a foundation for POST-emergence weed management in corn, cotton and soybean (Figure 3). For instance, it has been documented that within a soybean season, glyphosate is typically sprayed three times in Rio Grande do Sul state (RS, South region) (Ulguim et al. 2017).

Our survey suggests PRE herbicides use as not popular as burndown and POST herbicide programs (Table 4). PRE herbicides are costly, restricted due to intense crop succession/rotation (Reis et al. 2018) and typically not adopted in absence of HR weeds. In addition, cover crop residue from burndown applications in no-till systems

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result in a physical barrier that may either prevent germination of early-season weed species (Altieri et al. 2011) or prevent sprayed PRE herbicide reaching the soil (Christoffoleti et al. 2007), reducing either the need of PRE herbicide or the PRE herbicide efficacy on weeds.

Troublesome and HR weeds. Survey results indicate that the top five problematic weed species in Brazil are either glyphosate-tolerant (morningglory and dayflower) or GR (horseweed, sourgrass and goosegrass) (Figure 4). Distribution of troublesome (Figure 4) and GR weeds (Table 5) varied across regions. Although ranked amongst the most problematic grass weed because of high capacity to evolve resistance to herbicides (Preston et al. 2009), Italian ryegrass (*Lolium perenne* L. ssp. *multiflorum* Lam Husnot), a cool-season grass, is mainly adapted to the South region of Brazil (Table 5 and Figure 4). However, horseweed, an annual species adapted to no-till areas, is reported as the most widespread weed species presented in nearly 50% of soybeans cropland of Brazil (Lucio et al. 2019). Because of its intrinsic biology, horseweed seeds may reach the planetary boundary layer (140 m) reaching 500 km seed dispersal (Shields et al. 2006), which strongly contributes for the spreading of horseweed to adjacent and non-adjacent areas (Dauer et al. 2007). The seed-mediated flow also plays an important role in distribution of other herbicide resistance weeds. The first report of GR-Palmer amaranth and GR-sourgrass in South America were in Brazilian neighboring countries Argentina and Paraguay, respectively (Heap 2020). It is hypothesized that seeds from these two weed species migrated to Brazil through equipment, human traffic, and/or animals. For example, GR-sourgrass is widespread across Brazilian regions but was first reported in western Paraná (PR, south of Brazil) in 2016 near Paraguay (Ovejero et al. 2017). Genetic similarities within GR-sourgrass

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biotypes from Paraguay and Paraná were found but not with GR sourgrass biotypes from Southeast and Midwest (Takano et al. 2018), suggesting that evolution of GR-sourgrass is occurring through seed-mediated flow and independent selection.

GR weeds have been documented in orchard, cereal, and legume crops (Vila-Aiub et al. 2008), and are on the rise across Brazilian cropping systems. Nine weed species have evolved resistance to glyphosate in Brazil, including four monocots and five dicots (Brunharo et al. 2016; Heap 2020; Küpper et al. 2017; Takano et al. 2019). Recent reports have documented glyphosate failure to control slim amaranth (*Amaranthus hybridus* L.) (HRAC-BR 2019) and jungle rice (*Echinochloa colona* L. Link) (Pivetta et al. 2018) in Brazil. Other HR, including acetolactate synthase (ALS)-inhibitor herbicides are widespread in Brazil. For example, our data suggests that 87% of respondents are managing ALS-inhibitor resistant weeds in the South (Table 5), a region where ALS-inhibitor herbicides are a foundation for weed control in rice, wheat (*Triticum aestivum* L.), and soybean (Figure 4). Weed resistance to acetyl-CoA carboxilase (ACCase)-inhibitor herbicides is also a major problem in Brazil (Takano et al. 2019). The weed species plantain signalgrass (*Urochloa plantaginea* Link R. Webster), southern crabgrass (*Digitaria ciliaris* Retz. Koeler), goosegrass, Italian ryegrass, wild oats (*Avena strigosa* Schreb.), barnyardgrass (*Echinochloa crus-galli* L. P. Beauv.), and sourgrass have evolved resistance to ACCase-inhibitor herbicides (Heap 2020). The number of biotypes with multiple HR is increasing in Brazil, including goosegrass, barnyardgrass, and sourgrass with resistance to glyphosate, ACCase-, and/or ALS-inhibitor herbicides. Moreover, a horseweed biotype was reported resistant to 2,4-D, glyphosate, PSI-, photosystem II (PSII)-, and PPO-inhibitor herbicides (Heap 2020), which certainly increases the complexity of weed management in cropping

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systems where such biotypes are present.

New technologies. Our survey shows respondents willingness to adopt synthetic AR crops (57%) in Brazil (Table 5). Over 90% of growers surveyed in Nebraska reported weed management improve after using DR crops (Werle et al. 2018). Moreover, research has demonstrated effective control of pigweed species with dicamba (Schryver et al. 2017) and horseweed with 2,4-D (Frene et al. 2018). However, if adopted, dicamba or 2,4-D would have to be tank mixed with another herbicide for control of grass weed species given main weed problems in Brazil are GR grasses, such as sourgrass, goosegrass, and Italian ryegrass (Lucio et al. 2019). Studies documented that tank mixing 2,4-D (Li et al. 2020) or dicamba (Hart and Wax 1996; Underwood et al. 2016) can antagonize efficacy of ACCase-inhibitor herbicides such as clethodim for grass weed control, and higher rates of graminicides are needed to overcome antagonism. In addition, dicamba tank mixed with glyphosate reduces pH, resulting in increased dicamba concentration in the air following application (Mueller and Steckel 2019a, 2019b; Oseland et al. 2020). Therefore, 2,4-D and dicamba have little benefits and may complicate POST management of troublesome grass weed species besides the OTM concerns in Brazil.

The OTM of dicamba or 2,4-D leading to injury in sensitive vegetation is currently a major issue in the US (Knezevic et al. 2018; Kniss 2018; Soltani et al. 2020). Studies documented that dicamba concentration in the air following application increased with temperature (Jones et al. 2019; Mueller and Steckel 2019a). In Brazil, climatic conditions vary from tropical (with or without a dry season) to subtropical, with annual temperatures commonly > 30 C during soybean and cotton POST spray season (Alvares et al. 2013). In addition, dicamba or 2,4-D sensitive crops such as

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grape (*Vitis vinifera* L.), vegetables, orchards, soybean, cotton, and common bean (*Phaseolus vulgaris* L.) are commonly grown in Brazil. Micro-rates of dicamba or 2,4-D may cause visible injury on non-AR soybean (Osipitan et al. 2019), grape (Mohseni-Moghadam et al. 2016), and tomato (*Solanum lycopersicum* L.) (Knezevic et al. 2018). With AR crops, 2,4-D and dicamba herbicides are likely to be sprayed in large areas, which increases the chances of OTM onto sensitive vegetation. In Brazil, there are still no published data regarding potential OTM of new dicamba, minimal information regarding 2,4-D-choline formulation (Kalsing et al. 2018). Further studies are needed to evaluate the impact of spraying large areas with dicamba and 2,4-D choline under tropical conditions. With the introduction of synthetic AR crops in Brazil, spraying dicamba and 2,4-D may require restrictions and extra herbicide applicator training similar to what has happened in the US. Although it is not required in the country, nearly 70% of survey respondents indicated that applicators received some form of training (Table 6).

Limitations for Weed Management

As highlighted in our survey, HR weeds are a major constraint for crop management in Brazil (Table 7). Although Brazil has fewer documented cases of HR weeds when compared to Australia, Canada, and US (Heap 2020), the upcoming AR crops technologies do not address the current HR-grass weed problems in the country. Managing HR weeds in Brazil may require additional adoption of non-chemical strategies or introduction of new herbicide SOA effective on grass species. Brazilian growers already employ multiple effective non-chemical strategies, including cover crops, crop diversity, crop succession in season, no-till, and others (Table 5). A new non-chemical weed control strategy, harvest seed weed control (Walsh et al. 2018), is a

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valuable tool for minimizing HR weeds but to our knowledge is still not available nor evaluated/studied in Brazil. Nonetheless, the evolution of HR grass weed species and absence of new effective technologies are threatening the sustainability of Brazilian agricultural production.

Survey respondents reported industry as the main source of information for crop and weed management in Brazil (Table 7). Despite being incredibly valuable, industry information can be biased towards portfolios. In contrast, sources of unbiased information from basic and applied research are public institutions, including Universities, state Extension agencies and EMBRAPA (Brazilian Agricultural Research Corporation). Therefore, there is a need for an increase on collaborative work on basic and applied research in Brazil due to the upcoming weed herbicide resistance challenges and introduction of novel and complex to adopt technologies which will demand research and education for proper and effective adoption.

The survey results presented herein highlight the current status and the difference in cropping systems and weed management practices adopted across Brazil. Our survey showed the trends in conservation agricultural practices and advances the knowledge regarding current weed management strategies in Brazilian agriculture. Brazilian stakeholders are progressive in the sense of adopting conservation agricultural practices and new technologies. However, introduction of new technologies focused on the US (e.g., synthetic AR crops) for weed management may not address the major weed problems in Brazil but potentially generate a new challenge, OTM of herbicides into sensitive vegetation. Therefore, we urge that academics, growers, industry and policy makers: (1) expand monitoring of herbicide resistance weeds, (2) increase research on non-chemical weed management strategies, and (3) increase investments on

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public databases, surveys, basic and applied research to support decisions regarding the introduction and adoption of novel agricultural technologies.

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Conflicts of Interest

No conflicts of interest have been declared.

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Table 1. Survey questionnaire available online for agronomist, consultant, grower, industry and university representatives in the 2018 cropping systems weed management survey.

Q1) What is your role?
Q2) Which Brazilian state(s) do you manage cropping systems?
Q3) How many hectares managed/influence?
Q4) Which crop(s) do you manage/influence?
Q5) How many crop(s) in succession in the area you managed/influence?
Q6) Do you manage/influence irrigated systems?
Q7) Do you manage/influence no-till system?
Q8) Do you manage/influence cover crop? If Yes, which species?
Q9) Do you manage/influence crop-livestock integration system?
Q10) What is the most troublesome Weeds that you manage/influence?
Q11) Do you manage/influence area with glyphosate-resistant weeds?
Q12) Which glyphosate-resistant weeds do you manage/influence?
Q13) Do you manage/influence area with herbicide-resistant weeds (non-glyphosate)?
Q14) Which herbicide-resistant weeds do you manage/influence?
Q15) Which herbicide program and SOA is used in crops you manage?
Q16) Who is responsible for herbicide application in your operation?
Q17) Does the herbicide applicator receive pesticide application training?
Q18) Do you employ non-chemical weed management strategies?
Q19) Do you intend to adopt/recommend synthetic auxin crops (2,4-D or dicamba) in the area you manage/influence?

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Q20) What is your main source of information for weed management?
Q21) What is the main weed management limitation in the area you manage/influence?

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Table 2. Respondents demographics of the 2018 cropping systems weed management survey.

	Region					
Demographics	Brazil	North	Northeast	Midwest	Southeast	South
			———%———			
A. Respondents (n[a]=279)		4	8	23	38	43
B. ha managed (n=123)		9	6	43	41	14
total ha	5.7 mi					
C. Role (n=277)						
Agronomist	69	68	68	68	73	61
Consultant	9	0	14	16	13	3
Grower	21	18	5	22	24	17
Industry	22	45	36	35	26	13
University	22	18	18	11	26	22
Other	7	7	8	3	4	11

[a]number of respondents

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Table 3. Cropping system management strategies (no-tillage, cover crops, crop-livestock, crop succession and irrigation) adopted in Brazil according to the 2018 cropping systems weed management survey.

	Region					
Cropping systems	Brazil	North	Northeast	Midwest	Southeast	South
			——%——			
A. No-tillage[a]						
Yes	61	55	50	71	51	67
Partially	22	27	18	18	18	27
No	16	18	32	11	31	6
n^b	273	11	22	63	99	119
B. Cover crop						
Yes	61	55	55	58	52	68
No	39	45	45	42	48	32
n	273	11	22	7	99	119
C. Cover crop species						
Field mustard	16	0	5	7	14	17
Oats	48	0	5	7	50	50
Pearl millet	29	27	27	28	68	6
Perennial ryegrass	22	0	0	2	9	27
Spreading liverseed grass	27	27	27	37	68	4
Sunn hemp	27	0	14	28	91	5
Other	3	1	2	1	7	2

Table 3 continued from previous page

n	143	11	22	57	22	113
D. Crop-livestock integration						
Yes	37	45	14	46	22	48
No	63	55	86	54	78	52
n	256	11	22	57	93	114
E. Crop succession[c]						
1	29	9	36	7	27	34
2	41	64	41	74	43	29
3	30	27	23	20	29	37
n	271	11	22	61	99	119
F. Irrigation						
Yes	18	9	14	6	17	24
Partially	32	9	41	33	34	29
No	50	82	45	60	48	47
n	272	11	22	63	99	119

[a]Conservation tillage; [b]number of respondents; [c]number of growing crops within a year.

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Table 4. Herbicide program (burndown, PRE, POST and harvest aid) for weed management in multiple crops in Brazil according to the 2018 Cropping systems weed management survey.

Crops	Weed Management Program			
	Burndown	PRE	POST	Harvest aid
		——%——		
Corn (n[a]=119)	85	41	92	-
Cotton (n=23)	87	70	87	39
Coffee[b] (n=20)	35	25	85	-
Citrus[c] (n=19)	32	16	68	-
Common bean (n=57)	93	44	81	58
Eucalyptus[d] (n=15)	80	47	67	-
Rice (n=45)	91	76	93	-
Small grains[e] (n=30)	97	20	70	-
Sorghum[f] (n=22)	100	55	68	-
Soybean (n=159)	82	53	81	61
Sugarcane[g] (n=31)	71	87	77	-
Vegetables[h] (n=16)	69	50	69	-
Wheat (n=33)	100	33	94	30

[a]number of respondents; [b]*Coffea arabica* L., *Coffea canephora* Pierre ex Froehner; [c]*Citrus × sinensis* L. Osbeck; [d]*Eucalyptus* spp.; [e]barley, cereal rye, oats, triticale; [f]*Sorghum bicolor* L. Moench; [g]*Saccharum officinarum* L.; [h]carrot (*Daucus carota* L. var. sativus Hoffm.), garlic (*Allium sativum* L.), onion (*Allium cepa* L.)

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Table 5. Weed management status (herbicide weed resistance) and strategies (adoption of auxin-resistant crops and non-chemical control) in Brazil according to the 2018 cropping systems weed management survey.

Weed Management	Region					
	Brazil	North	Northeast	Midwest	Southeast	South
			——%——			
A. Glyphosate resistance						
Yes	74	73	64	79	73	80
Not sure	12	18	27	12	13	7
No	14	9	9	9	14	13
n^a	258	11	22	57	94	114
B. Glyphosate resistant weeds						
goosegrass	31	50	43	44	28	25
horseweed[b]	82	88	79	71	79	91
Italian ryegrass	28	13	14	9	10	54
Palmer amaranth	2	0	4	4	1	0
sourgrass	56	75	79	91	82	25
tall windmill grass[c]	7	13	7	7	6	9
n	190	8	14	45	67	91
C. Other herbicide resistance						
Yes	46	55	50	79	37	54
Not sure	24	36	23	12	29	19
No	30	9	27	9	34	26

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Table 5 continued from previous page

n	257	11	22	57	94	114
D. Herbicide resistance SOA[d]						
ALS[e] inhibitor	78	50	63	76	73	87
ACCase[f] inhibitor	31	50	63	44	46	21
HPPD[g] inhibitor	7	25	38	0	12	2
LCFA[h] inhibitor	4	25	13	0	8	2
PSI[i] inhibitor	13	0	38	8	23	10
PSII[j] inhibitor	12	25	38	16	19	6
PPO[k] inhibitor	11	50	13	16	19	10
Synthetic auxin	13	25	13	0	8	2
n	97	4	8	25	26	52
E. Adoption of AR[l]-crops						
Yes	57	56	54	60	64	55
Partially	34	33	23	21	20	42
No	9	11	23	19	16	3
n	154	9	13	42	44	74
F. Non-chemical weed control						
Biological	5	0	6	2	3	6
Cultural	71	100	33	77	65	76
Mechanical	45	25	50	33	58	41
Physical	15	13	0	2	12	24
None	15	0	31	14	15	14
n	192	8	16	43	66	87

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[a]number of respondents; [b]asthmaweed, Canadian horseweed and tall fleabane; [c]*Chloris elata* Desv; [d] SOA, site of action; [e]ALS (acetolactate synthase); [f]ACCase (acetyl-CoA carboxilase); [g]HPPD (4-hydroxyphenylpyruvate dioxygenase); [h]LCFA (long-chain fatty acid); [i]PSI (photosystem I); [j]PSII (photosystem II); [k]PPO (protoporphyrinogen oxidase); [l]auxin-resistant.

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Table 6. Herbicide application information in Brazil according to the 2018 cropping systems weed management survey.

Herbicide application	Region					
	Brazil	North	Northeast	Midwest	Southeast	South
A. Responsible for application			———%———			
Ag technician	17	22	24	20	20	19
Agronomist	30	67	47	30	40	19
Applicator specialist	21	44	18	32	24	15
Co-op	3	0	0	0	4	4
Grower	50	56	41	32	36	71
Farm employees	50	33	29	68	56	38
n^a	202	9	17	44	70	91
B. Herbicide application training						
Yes	69	89	64	84	81	56
Not sure	16	11	18	7	10	21
No	15	0	18	9	9	23
n	202	9	17	44	70	91

[a]number of respondents

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Table 7. General questions regarding weed management strategies in Brazil according to the 2018 cropping systems weed management survey.

General questions	Region					
	Brazil	North	Northeast	Midwest	Southeast	South
A. Limitations			——%——			
Costs	53	63	81	32	56	47
Limited herbicide options	38	0	35	21	34	38
Labor	18	0	13	7	15	20
Legislation	30	25	13	13	29	31
Weed resistance	69	75	56	38	59	78
n^a	198	8	16	90	68	90
B. Source of information						
Consultant	30	44	25	38	35	24
Embrapa[b]	43	11	31	41	42	49
Industry	54	78	31	55	65	50
University	52	44	56	48	52	56
State entities	43	22	38	48	36	47
n	199	9	16	44	69	90

[a]number of respondents; [b]Brazilian Agricultural Research Corporation.

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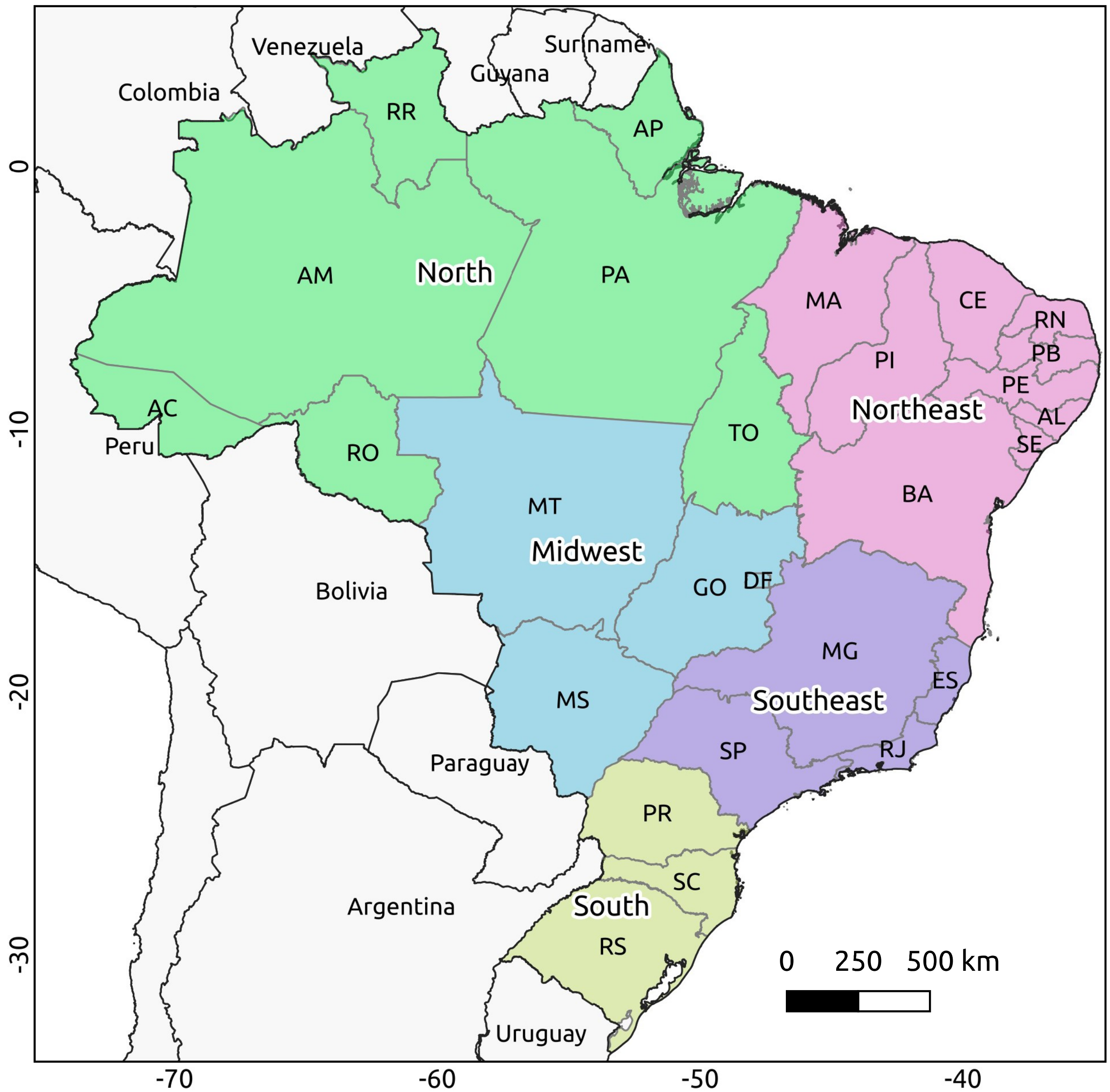

Figure 1. Brazilian map highlighing the five geopolitic macro-regions: North, Northeast, Midwest, Southeast and South.

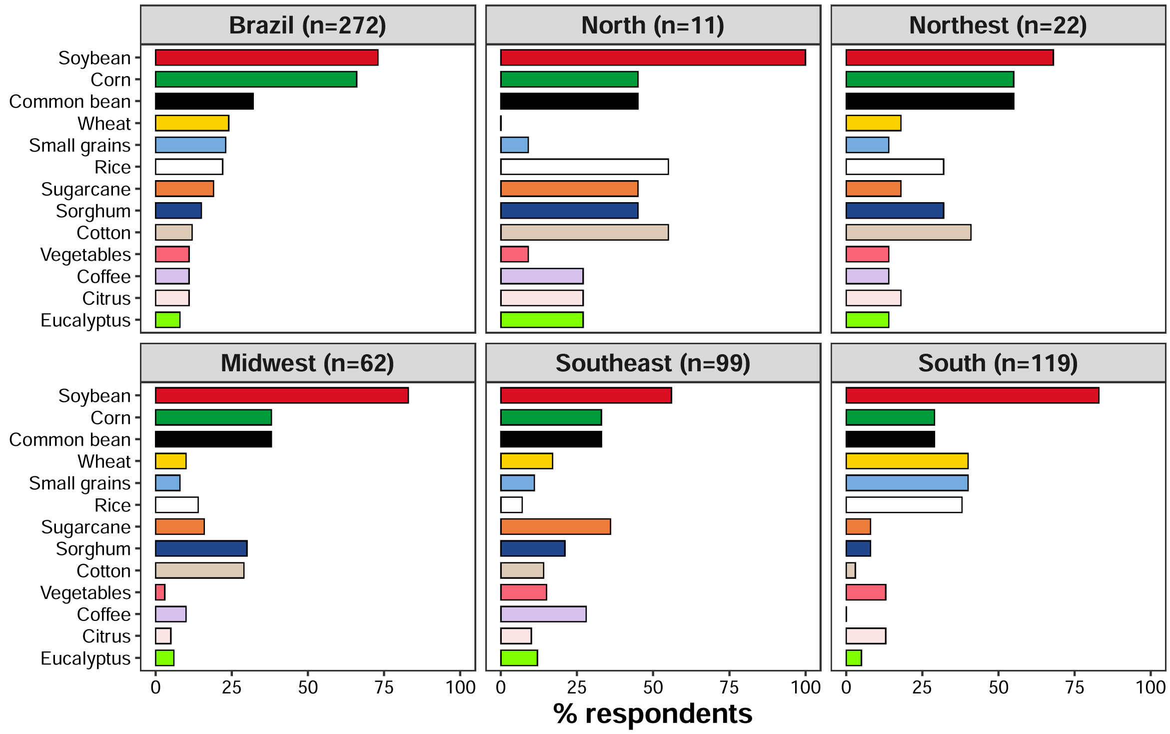

Figure 2. Percentage of respondents managing crops by Brazilian regions according to the 2018 cropping systems weed management survey (n = number of respondents). Coffee (*Coffea arabica* L., *Coffea canephora* Pierre ex Froehner), Citrus (*Citrus* × *sinensis* L. Osbeck), Eucalyptus (*Eucalyptus* spp.), Small grains (barley, cereal rye, oats, triticale), Sorghum (*Sorghum bicolor* L. Moench), Sugarcane (*Saccharum officinarum* L.), Vegetables (carrot [*Daucus carota* L. var. sativus Hoffm.], garlic [*Allium sativum* L.], onion [*Allium cepa* L.]).

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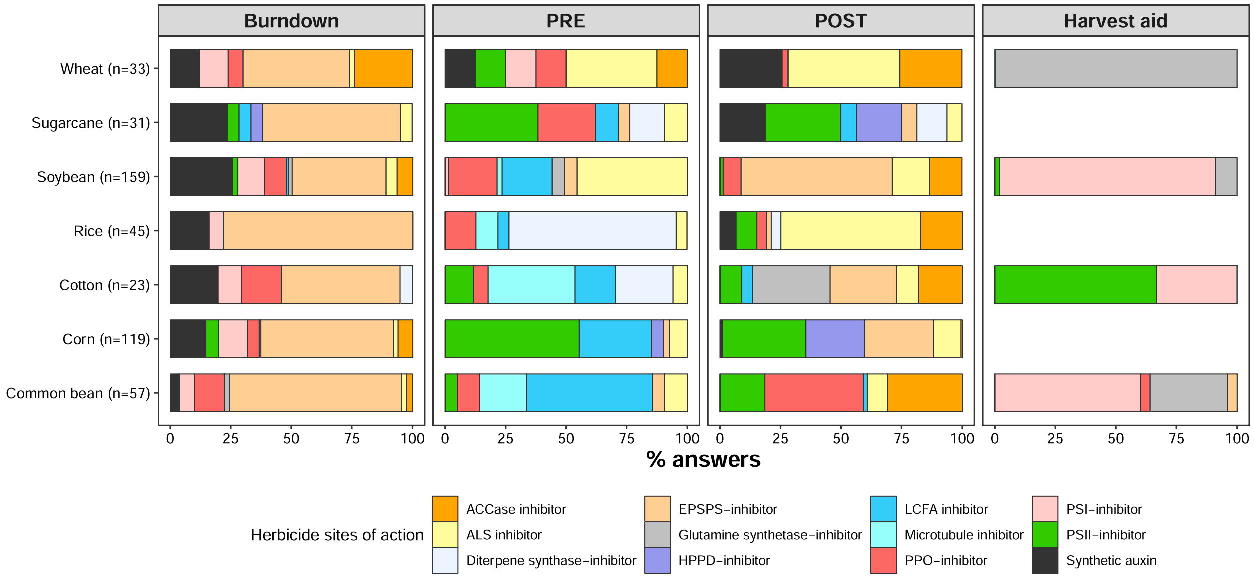

Figure 3. Percentage of answers by survey respondents on herbicide site of action use on common bean, corn, cotton, rice, soybean, sugarcane (*Saccharum officinarum* L.) and wheat in burndown, PRE, POST, and harvest aid programs according to the 2018 cropping systems weed management survey (n = number of respondents). ALS (acetolactate synthase), ACCase (acetyl-CoA carboxilase), HPPD (4-hydroxyphenylpyruvate dioxygenase), LCFA (long-chain fatty acid), PSI (photosystem I), PSII (photosystem II), PPO (protoporphyrinogen oxidase).

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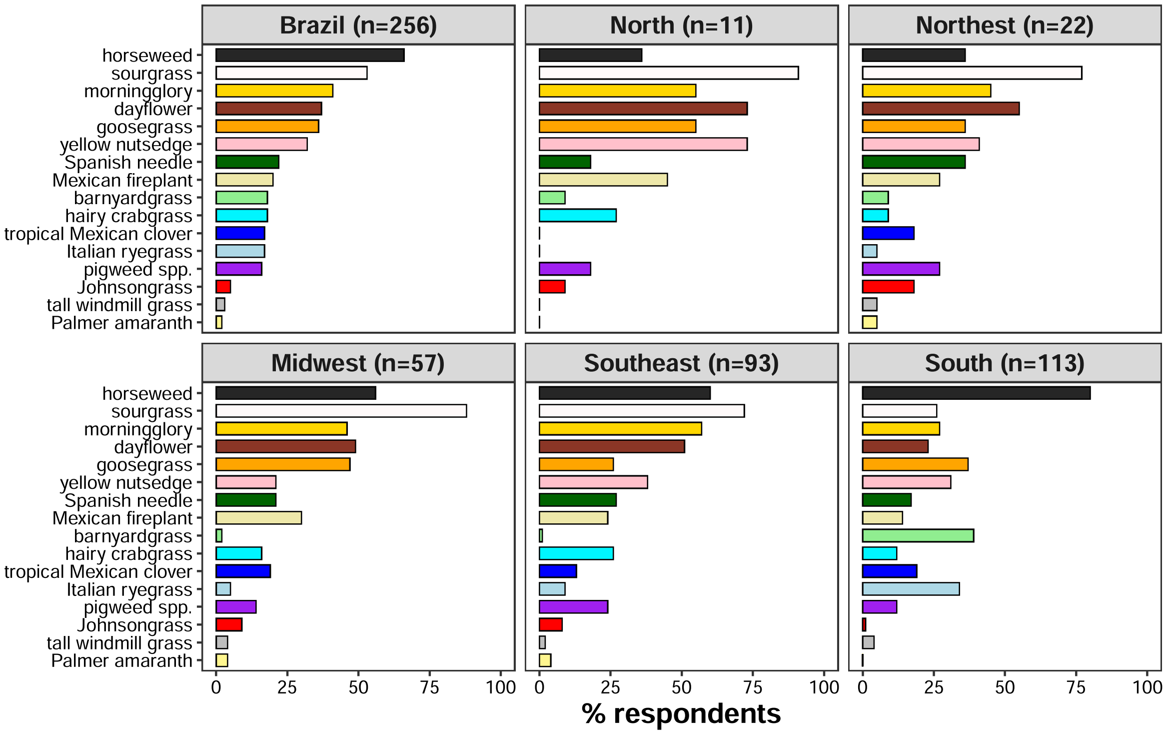

Figure 4. Percentage of respondents managing troublesome weeds by Brazilian regions according to the 2018 cropping systems weed management survey (n = number of respondents). Dayflower (Asiatic dayflower and Benghal dayflower), hairy crabgrass (*Digitaria sanguinalis* L. Scop), horseweed (asthmaweed, Canadian horseweed and tall fleabane), Johnsongrass (*Sorghum halepense* L. Pers), Mexican fireplant (*Euphorbia heterophylla* L.), pigweed sp. (*Amaranthus* spp.), Spanish needle (*Bidens* spp.), tall windmill grass (*Chloris elata* Desv), tropical Mexican clover (*Richardia brasiliensis* Gomes), yellow nutsedge (*Cyperus esculentus* L.).