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Identification of Weed Species in Commercial Soybean Areas by High-Resolution Drone Images

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Abstract

Multispectral sensors onboard remotely piloted aircraft systems (RPAs) can be used for mapping and identifying weed species and preventing crop yield losses. The objective of this study was to identify and quantify weed species in soybean using high-resolution images obtained by an RPA. Soybean fields were photographed 33 times every 100 ha. Weed flora in 384 sampling areas was surveyed by aerial imaging in approximately 60.000 ha. Results on analysis of the community structure of the observed a total of 16 plant families and 52 species. Species from Asteraceae and Poaceae were the most numerous. Results of principal component analysis showed that the percentage of infestation and the number of species were positively correlated to the first component. The areas with the highest percentage of infestation had the highest diversity of species. However, the percentage of infestation and the number of species observed were not correlated with the area size. The survey of weeds by aerial imagery was efficient for identifying, quantifying, and mapping weeds in commercial agricultural areas and can be used in other studies and for the purposes of management in commercial areas.

Keywords: management, remote sensing, soybean, weed science

1. Introduction

Weeds are a major yield-limiting problem in the production of fibers, food, and fuel worldwide. Several weed species can affect crop yield, quality of harvested products, mechanized harvest, and development of insect pests and diseases (Oerke 2006; Owen, 2016). Spatial distribution and diversity of weeds vary according to the species of cultivated plants, region, and adopted management methods (Jabeen & Ahmed, 2009; Vigueira et al., 2013; Iqbal et al., 2015). Weed control typically consists of frequent and systematic applications of chemical herbicides, which can pose a serious threat to sustainability (Geiger et al., 2010; Mcelroy, 2014). Continued use of herbicides can change weed communities, potentially selecting resistant weed biotypes (Owen, 2016; Silva et al., 2018).

The use of integrated management techniques for weed management can lead to more sustainable crop production and effective protection against crop yield losses. One of the most innovative techniques within smart weed management programs consists of using remotely piloted aircrafts (*i.e.*, RPAs or drones). Multispectral sensors onboard RPAs can be used for mapping and identifying individual weed plants and species (Liakos et al., 2018). These RPAs can operate at low altitudes, even on cloudy days, and provide an ultra-high spatial resolution of the entire production area (Peña et al., 2015). Flight plans can be scheduled on-demand with great flexibility to collect remote images of crops at critical moments of competition. Thus, RPAs can be very useful instruments in farmers' decision-making for weed control in the correct location and time (Lelong et al., 2008).

The objective of this study was to identify and quantify weed species in soybean using high-resolution images obtained by an RPA.

2. Material and Methods

2.1 Study Area

The study covered a large commercial soybean region of the state of Goiás, Brazil, representing 384 sampling areas distributed across 16 municipalities during 2017/18 summer growing season (Figure 1). The size of the areas varied between 100 and 250 hectares. All evaluated sampling areas were cultivated with a no-till system and glyphosate application at least two times a year.

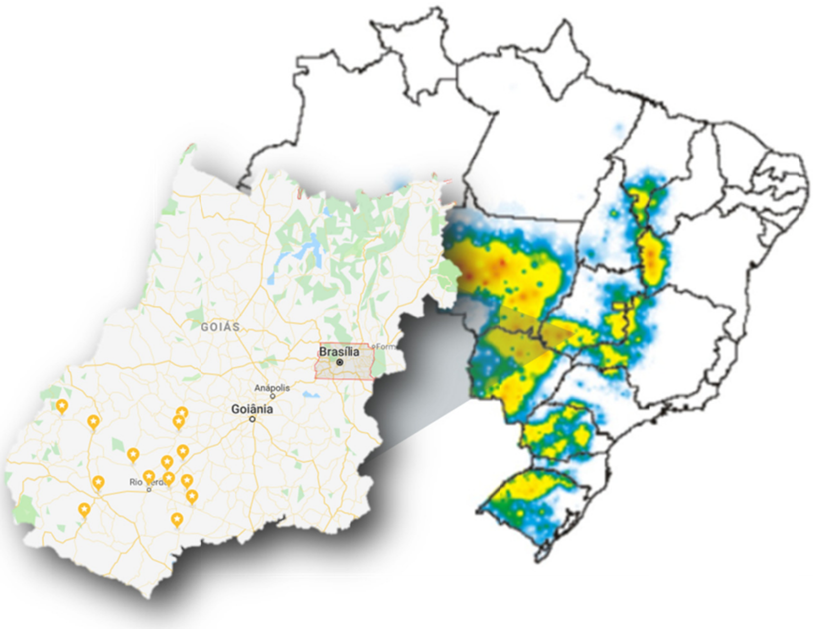


Figure 1. Map of 16 municipalities in southwest Goiás, Brazil, used during the floristic survey of weeds in 384 sampling areas (colors in the underneath map represent soybean production intensity)

Source: Google Maps and Bayer Cropscience.

2.2 Floristic Survey of Weed Species

A total of 384 sampling areas were randomly photographed at 3 m of altitude using a commercial quadcopter RPA (Strix-Ag, Skydrones, Brazil). Single-shot images were obtained by setting the drone to fly 33 times every 100 ha using the WeedScouting software (Skydrones, Brazil). Images were recorded using a 12-megapixel RGB camera, 20 mm focal length, and without distortion or fisheye look (ZENMUSE X3). A 3-axis gimbal was used to stabilize the camera during photographs. Images were recorded between 8:00 am and 1:00 pm with up to 10% of cloud cover. Flights occurred before and after weed desiccation (*i.e.*, around preparation for sowing soybean seeds). An analysis of the weed community structure was conducted up to species level. Weeds within every image were counted and identified by comparing with those described by Kissmann and Groth (1997, 1999, 2000), and Kinupp and Lorenzi (2014). The distribution of species by municipality and its relationship with precipitation, divided into ten-day periods, from October to December, was generated to demonstrate the predominance of species through the amount of rainfall.

2.3 Whole-Field Classification of Weed Infestation

Fields were also flown by another RPA (eBee Classic, SenseFly, Brazil) using 70% photo lateral and frontal overlaps and the same 20-megapixel RGB camera. Ground sampling distance was 2.8 cm per pixel. The classification method used was that of machine learning developed by Basf Digital Farming Solutions, where the displacement of each weed could vary up to a maximum of 1 m and the final percentage was given at 10 cm per pixel. Supervised classification of the images was conducted by an analyst with knowledge in systematics and plant taxonomy. The collected database of plants, soil, straws, weeds, and non-weed pixels was separated for training (80%) and validation (20%). The analyst configured the algorithm to distinguish plants within the community based on pre-established statistical rules (Venturieri, 2007; Vale et al., 2018). The analyst selected representative training areas from each class by segmenting polygons by color and size on the video monitor. Several training areas were defined for the same class. The identification of the images was systematically conducted, adapted to three levels of taxonomic identification. Level one represents class and was comprised of Eudicotyledons (Class Magnoliopsida) and Monocotyledons (Class Liliopsida). Level two represents family and was comprised of 12 Families (Amaranthaceae, Asteraceae, Brassicaceae, Commelinaceae, Convolvulaceae, Cyperaceae, Euphorbiaceae, Fabaceae, Malvacea, Poaceae, Rubiaceae and Solanaceae). Level three represents species was comprised of specimens with flower or field validation.

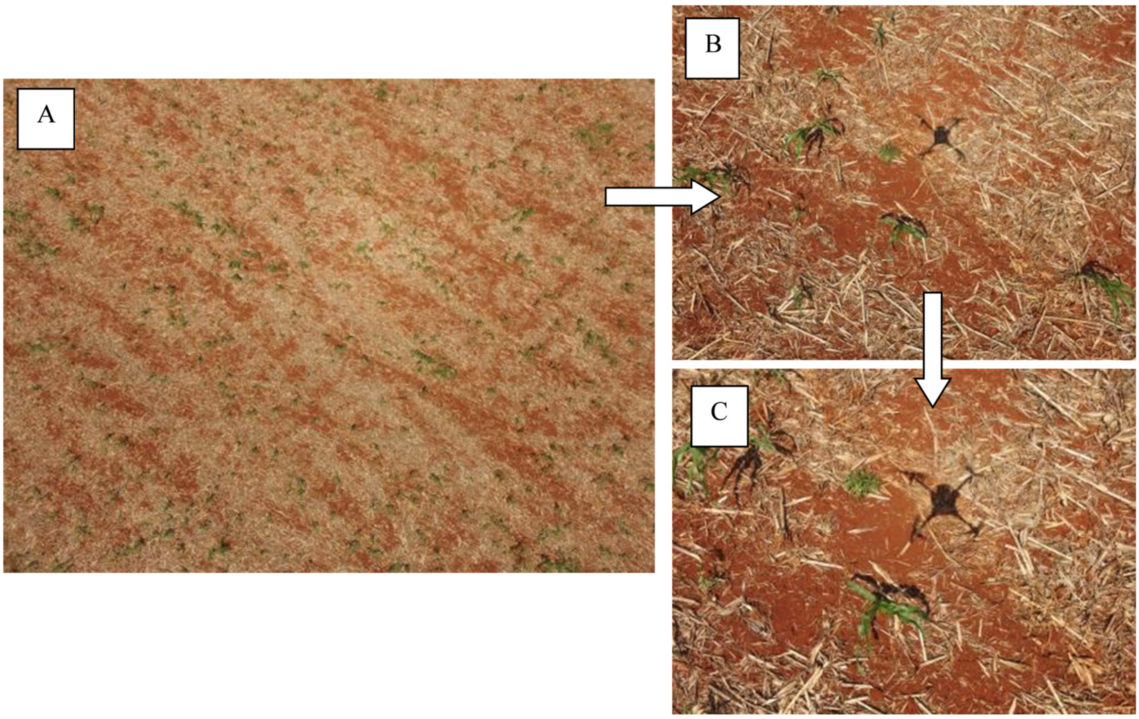


Figure 2. Image collected for identification in commercial area (A), drone approach to capture the photo at 3 meters (B), Image enlarged for identification (C). Photos: Digital Farming 2017

2.4 Univariate and Multivariate Statistical Analyses

Data obtained were organized by order, family, and species of weeds. The frequency was recorded in more than ten plots. Pearson's correlation test was used to associate infestation level and rainfall. Cluster method was used to evaluate overall data using the interdependence technique to group the elements according to their structure, generating a principal component analysis (PCA). Cluster method was applied to evaluate the data using the interdependence technique to group the elements according to their structure, generating a principal component analysis (PCA), in order to explain the structure of variance and covariance, composed of p-random variables, through linear combinations of the original variables (Manly, 1986). The analyses of this study were carried out through computational routines implemented in R software 3.0.1 (R Development Core Team, 2018).

3. Results and Discussion

A total of 16 plant families and 52 species were identified. Ten species belonged to the family Asteraceae and 12 to the family Poaceae (Table 1 and Figure 3). These two families typically represent most of the weed community in the state of Goiás (Silva et al., 2015). Poaceae and Asteraceae comprise more than 50% of the plant species in the world (Holm et al., 1997), which may contribute to the higher relative densities detected, consequently implying the highest phytosociological values observed for these families. Invasive plants considered secondary were represented by plants of the families Amaranthaceae, Euphorbiaceae, and Malvaceae. Lower representativeness was observed for the families Apocynaceae, Brassicaceae, Portulacaceae, Phyllanthaceae, Sapindaceae, Solanaceae, and Commelinaceae (Table 1). Several factors can influence weed diversity, including physical and biological variables, agronomic practices, soil tillage, crop rotation, and the use of herbicides (Silva et al., 2018).

Table 1. Floristic list of weed species in the southwest state of Goiás evaluated during the 2017/2018 growing season

Class	Family	Species
Eudicotyledons	Amaranthaceae	*Alternanthera tenella* (joyweed), *Amaranthus deflexus* (perennial pigweed), *A. hybridus* (smooth pigweed), *A. retroflexus* (redroot pigweed), *A. viridis* (slender amaranth), *Chenopodium album* (fat hen)
	Apocynaceae	*Peschiera fuchsiaefolia* (“leiteiro”)
	Asteraceae	*Acanthospermum hispidum* (bristly starbur), *Ageratum conyzoides* (tropic ageratum), *Bidens pilosa* (hairy beggarticks), *Chaptalia nutans* (língua-de-vaca), *Conyza bonariensis* (hairy fleabane), *C. sumatrensis* (sumatran flebane), *Emilia sonchifolia* (red tasselflower), *Gamochaeta coarctata* (gray everlasting), *Sonchus oleraceus* (annual sowthistle), *Tridax procumbens* (coat buttons)
	Brassicaceae	*Lepidium virginicum* (virginia pepperweed)
	Caricaceae	*Carica papaya* (papaya)
	Convovulaceae	*Ipomoea* spp. (morning glory)
	Euphorbiaceae	*Euphorbia heterophylla* (wild poinsettia)
	Fabaceae	*Crotalaria spectabilis* (showy crotalaria), *Glycine max* (soybean), *Senna obtusifolia* (sicklepod), *S. occidentalis* (coffee senna)
	Lythraceae	*Cuphea hyssopifolia* (false heather)
	Malvaceae	*Malvastrum coromandelianum* (false mallow), *Sida cordifolia* (flannel weed), *S. glaziovii* (guanxuma-branca), *S. spinosa* (prickly sida).
	Melastomataceae	*Clidemia hirta* (koster's curse)
	Phyllanthaceae	*Phyllanthus tenellus* (long-stalked phyllanthus)
	Portulacaceae	*Portulaca oleracea* (common purslan)
	Rubiaceae	*Borreria latifolia* (broadleaf buttonweed), *Richardia brasiliensis* (Brazil pusley), *Spermacoce verticillate* (shrubby false buttonwood)
	Sapindaceae	*Cardiospermum halicacabum* (balloon vine)
	Solanaceae	*Nicandra physaloides* (apple of Peru)
Monocotyledons	Commelinaceae	*Commelina benghalensis* (wandering jew)
	Cyperaceae	*Cyperus iria* (rice flatsedge), *C. rotundus* (purple nutsedge).
	Poaceae	*Brachiaria decumbens* (signalgrass), *Cenchrus echinatus* (southern sandbur), *Digitaria insularis* (sourgrass), *Eleusine indica* (goosegrass), *Melinis repens* (natal redtop), *Panicum maximum* (guineagrass), *Pennisetum setosum* (mission grass), *Rottboellia cochinchinensis* (itchgrass), *Saccharum officinarum* (sugarcane), *Sorghum halepense* (johnsongrass), *Urochloa plantaginea* (marmeladegrass), *Zea mays* (maize)

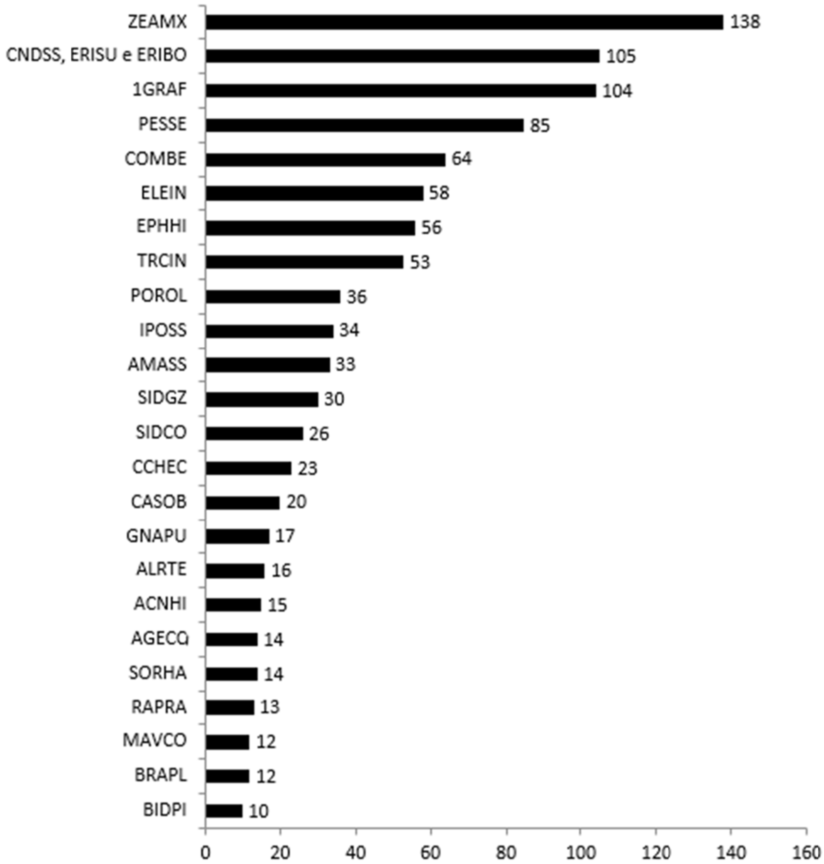
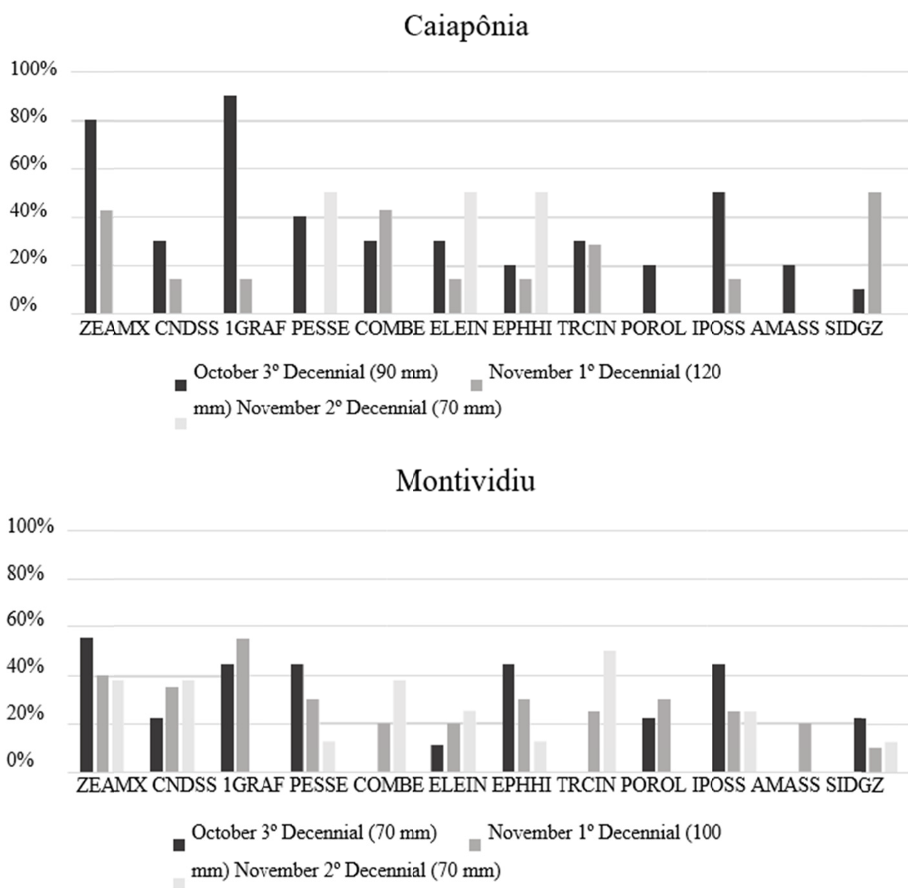


Figure 3. Species and Family (EPPO code Global, 2019) found in 384 sampling areas in the southwest state of Goiás, 2017/2018 season. ZEAMX: *Zea mays*; CNDSS: *Conyza* sp.; ERISU: *C. sumatrensis*; ERIBO: *C. bonariensis*; 1GRAF: Poaceae; PESSE: *Pennisetum setosum*; COMBE: *Commelina benghalensis*; ELEIN: *Eleusine indica*; EPHHI *Euphorbia hirta*; TRCIN: *Digitaria insularis*; POROL: *Portulaca oleracea*; IPOSS: *Ipomea* sp.; AMASS: *Amaranthus* sp.; SIDGZ: *Sida glaziovii*; SIDCO: *S. cordifolia;* CCHEC: *Cenchrus echinatus*; CASOB: *Senna obtusifolia*; GNAPU: *Gamochaeta coarctata*; ALRFI: *Alternanthera tenella*; ACHNI: *Acanthospermum hispidum*; AGECO: *Ageratum conyzoides*; SORHA: *Sorghum halepense*; RAPRA: *Raphanus raphanistrum* ; MAVCO: *Malvastrum coromandelianum*; BRAPL: *Urochloa plantaginea*; BIDPI: *Bidens pilosa*

The high number of weed plants indicated a failure in weed management, including resistance of weeds to improperly used herbicides, applications in inadequate environmental conditions, or lack of integrated control (Bianchi et al., 2006). However, the number of weed species seemed to be lower than that of previous years (Santos et al., 2018). Low diversity is typically a result of monoculture with a strong dependence on chemical herbicides, which can impose a strong selection pressure for resistant weed plants. Therefore, diversifying the selection of control methods in this region may prevent the dominance of one or few weed species (Neve et al., 2018). Main weed species observed in sampling areas were *Z. mays*, *Conyza* sp., *P. setosum*, *C. benghalensis*, *E. indica*, *D. insularis*, *Ipomea* sp. and *Amaranthus* spp. (Table 2). These species are commonly found in phytosociological surveys of weeds (López-Ovejero et al., 2016, Gazola et al., 2016; Minozzi et al., 2017; Ovejero et al., 2017; Almeida et al., 2017; Santos et al., 2018; Souza and Lacerda et al., 2019). *Conyza* sp., *D. insularis*, *E. indica*, *C. benghalensis,* and *E. heterophylla* occurred in low frequency (Figure 3), but are important to be considered in weed management because of the several herbicide-resistant biotypes reported throughout the world and transmission of the maize mosaic polyvirus (Heap, 2009; Perotti et al., 2019). Constant weed monitoring is important for preventing economic losses from these highly adapted weed species.

The coexistence of volunteer corn plants can cause direct and indirect crop yield losses by up to 70% (Deen et al., 2006). Volunteer corn also has a staggering germ flow that prevents localized control methods. Volunteer corn was the weed most frequently observed in the sampled areas. It was recorded in 138 out of the 384 sampling areas (Figure 3). Soybean produced in Brazil is predominantly sown over the straws of the previous crop. The straws generally come from corn. The highest incidence of volunteer corn occurred in São João da Paraúna, Acreúna and Serranópolis (Figure 5). These municipalities typically invest lesser in human and crop resources, typically with a succession between soybean and corn only. Glyphosate-resistant plants are difficult to control in these municipalities because of the limited chemical alternatives for desiccation in no-till systems (Karam, 2007, Alvarenga et al., 2018).

Water stored in the soil and protected by straws is one of the most important resources for weeds and crops. The competition may cause stress and ultimately reduce growth and crop yield (Rizzardi et al., 2001). The variability of species identified in the three ten-day periods according to rainfall, through uniformity in the initial period of the growing season, is shown in Figure 4. The highest frequency of species observed in the ten-day periods in Caiapônia, Montividiu and Rio Verde, were found those belonging to the family Poaceae, however, it was not possible to identify up to the species level of each microregion according to the increase in rainfall per ten-day period. Rainfall was indicated as an agent of the great variability of species identified in the three ten-day periods, using uniformity in the initial period of the growing season (Figure 4). Making clear the importance of further studies on the separation in the volume of weeds in soybean sowing.



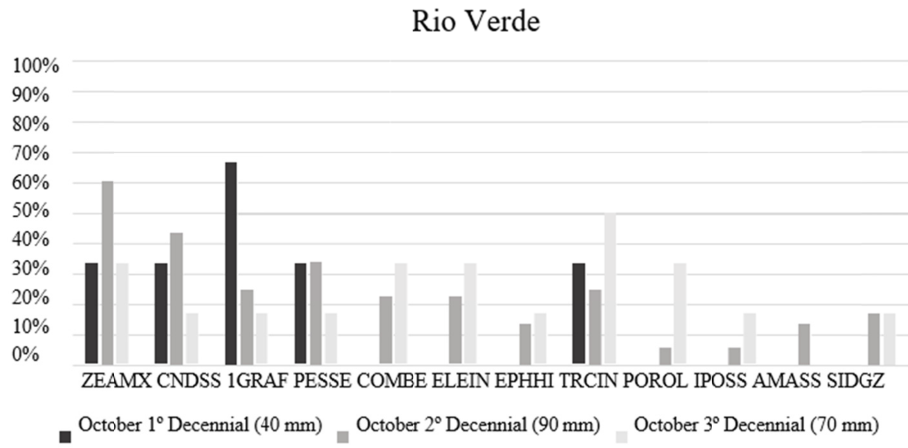


Figure 4. Percentage of weed prevalent (EPPO code Global, 2019) (x-axis) according to rainfall (y-axis), following the planting calendar of producers from Caiapônia, Montividiu and Rio Verde, 2017/2018 agricultural harvest. ZEAMX: *Zea mays*; CNDSS: *Conyza* sp.; 1GRAF: Poaceae; PESSE: *Pennisetum setosum*; COMBE: *Commelina benghalensis*; ELEIN: *Eleusine indica*; EPHHI *Euphorbia hirta*; TRCIN: *Digitaria insularis*; POROL: *Portulaca oleracea*; IPOSS: *Ipomea* sp.; AMASS: *Amaranthus* sp.; SIDGZ: *Sida glaziovii*

In the municipalities of Acreúna, Jatai, Quirinópolis, São João da Paraúna, and Turvelândia, species showing high infestation in the evaluated fields were C*onyza* sp., *Amaranthus* sp., *Ipomea* sp., *C. hirta*, *C. benghalensis*, *S. glaziovii, P. oleracea*, with an increase in the percentage of individuals per species only in the first ten-day period and a reduction in the two following ten-day periods. In Acreúna and São João da Paraúna, some poaceae species were superior to the other species, this may have occurred due to the initial cumulative rainfall of 70 mm in the first evaluation.

In Castelândia, Doverlândia, Paraúna, Santa Helena de Goiás, Santo Antônio da Barra and Serranópolis, evaluations were carried out only in the first ten-day period following the planting window of the monitored farmers. There was a greater variety of species in the municipalities of Paraúna, Doverlândia, Santa Helena de Goiás and Serranópolis. With a high number of species of the families Poaceae, Amaranthaceae, Asteraceae and Euphorbiaceae.

In the municipalities of Castelândia and Santo Antônio da Barra, there was a difference in plant density in the other municipalities, in which the predominant families were Poaceae and Asteraceae. This occurrence of low species incidence in both municipalities was higher, favoring the development of more aggressive species such as Poaceae.

In the municipalities of Palminópolis and Porteirão, there was a greater predominance of the family Poaceae, with only one species of Convovulaceae (*Ipomoea* sp.) among the sampling areas.

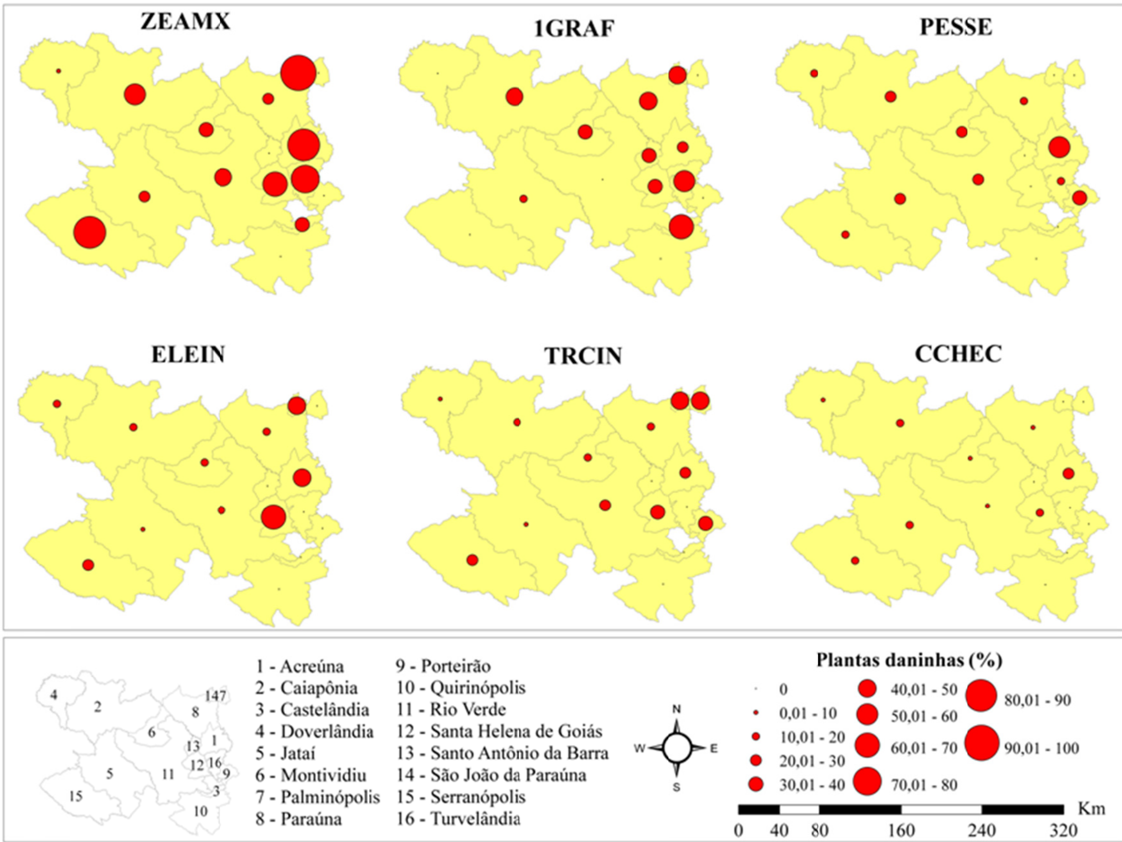


Figure 5. Occurrence of the six predominant monocotyledonous weed species (EPPO code Global, 2019), according to the collection municipality, following the planting calendar of producers in southwest state of Goiás, 2017/2018 growing season

Higher percentages of ELEIN incidence were found in Santa Helena de Goiás, Acreúna and São João da Paraúna (Figure 5). Higher percentages of TRCIN infestations were found in the municipalities of São João da Paraúna and Palminópolis, in which biotypes of this species have already been identified with a record of resistance to glyphosate (Melo et al., 2015). Thus, it is suspected that the high incidence of this species in these two municipalities may be the result of the exclusive use of glyphosate, even after low efficiency in control, combined with the presence of resistant individuals, favorable climate for the development of this infesting species and the dispersal capacity of propagules, since both municipalities are neighbors (Zobiole et al., 2016).

For PESSE, there was a higher percentage of infestation in the municipality of Acreúna. Higher incidence of grass offered in crops in this region may be related to the selection of resistant biotypes by the routine use of glyphosate and to climatic conditions, whose species is widely adapted (Silva and Silva, 2007). Timossi et al. (2016) indicated the occurrence of failures in the control of this species in the southwest state of Goiás, when tembotrione was used, whereas they were successful with the use of nicosulfuron.

Weeds present in the family Poaceae (1GRAF) demonstrate a higher percentage of infestation in the municipality of Castelândia (60.01 to 70.00%), followed by the municipalities of Turvelândia (50.01 to 60.00), São João da Paraúna, Paraúna and Caiapônia (40.01 to 50.00%). The greatest infestation of these in the municipality of Castelândia was registered in the 3rd ten-day period, with a cumulative rainfall of 120 mm, corroborating Corrêa et al. (2010) in Castelândia for individuals of the family Poaceae.

It was noticeable the difficulty in adapting and developing PESSE in relation to the other species, due to the low infestation recorded, which can be explained by the production system used in these regions, including reduced soil tillage techniques (Rosa-Filho et al., 2018).

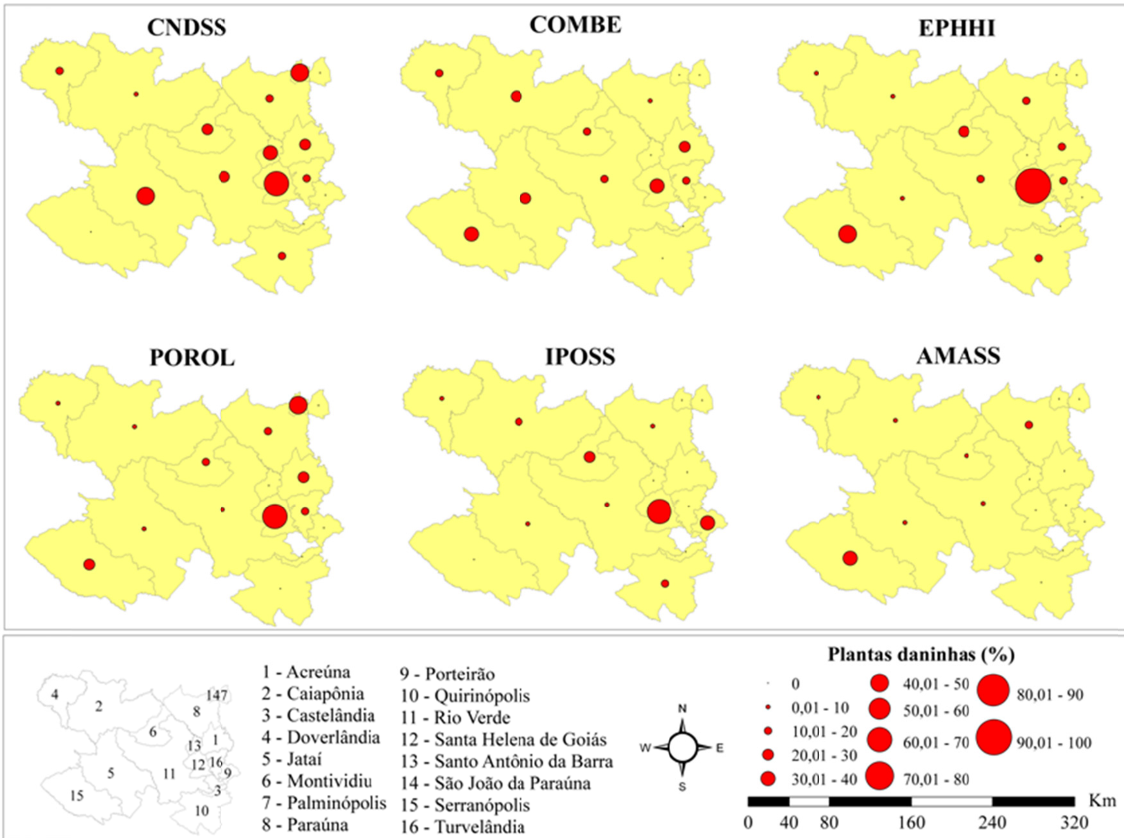


Figure 6. Occurrence of the six predominant monocotyledonous weed species (EPPO code Global, 2019), according to the collection municipality, following the planting calendar of producers in southwest state of Goiás, 2017/2018 growing season

The highest incidence of COMBE was found in Santa Helena de Goiás and Serranópolis (Figure 6), which may be related to the cultivation system (no-till) and to the lack of knowledge of the need to raise the dose of glyphosate to control this species, since studies already indicate its tolerance to glyphosate, which in turn is the most widely used herbicide in these regions (Pacheco et al., 2016).

The greatest infestations found were POROL, EPHHI, IPOSS and CNDSS, respectively, for the municipality of Santa Helena de Goiás, where percentages of 60.01 and 70.00% were observed, for POROL, IPOSS and CNDSS, and from 90 to 100% for EPHHI. The high infestation verified in Santa Helena de Goiás is certainly related to the non-integration of weed management methods and the routine succession of crops, favoring the selection of weeds that are difficult to control and, consequently, their multiplication and dispersion in agricultural areas of this municipality (Figure 6).

The highest percentage of 1AMAG infestation was in the municipality of Serranópolis, however, below 50%. Although it is a medium to difficult control plant, studies by Martins et al. (2016) show that the use of mulch in winter significantly reduces the population of *A. hybridus*. Carvalho and Christoffoleti (2007) show that 1AMAG species respond differently to light and temperature stimuli to germinate, so the 1AMAG infestation in Serranópolis may be associated with poor straw distribution, promoting low soil cover, high temperature and solar incidence in the region.

Table 2. Correlation matrix of related variables using data from the 2017/2018 growing season as reference. The dimensions of the principal component analysis were made with a significance of $p < 0.05$. P_infest: infestation percentagem, T_area: area size

Variables	PCA 1	PCA 2
P_infest	0.81	-0.24
Species	0.82	0.16
T_area	0.06	0.97
Municipality	0.13	0.02
Explained Variance	45.03	34.46
Cumulative Variance	45.03	79.49

The PCA analysis showed that the first two components explained 79.05% data variance (Table 2). The percentage of infestation and the number of species were positively correlated to the first component (PCA1), where the areas with the highest percentage of infestation were those with the highest diversity of species, indicating poorly managed areas and monoculture. Both the percentage of infestation and the number of species observed were not correlated with variables related to the area size. Thus, it was possible to notice that the area size and number of species behaved differently even on the same plane and axis, indicating a directly disproportionate relationship (Figure 7), which can be interpreted as concise variables. PCA was also used to identify groups of weed species and associate them with the management used in their respective areas. This analysis was chosen with an exploratory tool as it allows to identify relatively independent sets (principal components) of correlated variables.

There was no difference in the number of species in relation to the size of the area in most of the evaluated municipalities, this phenomenon can be explained by the predominant planting system, control and cultivation practices carried out in southwest state of Goiás. Except for some municipalities such as Montividiu, Caiapônia and Acreúna, where it was possible to notice a large number of species regardless of the size of the evaluated area, possibly caused by the initial accumulation of rainfall during the evaluation and control stage.

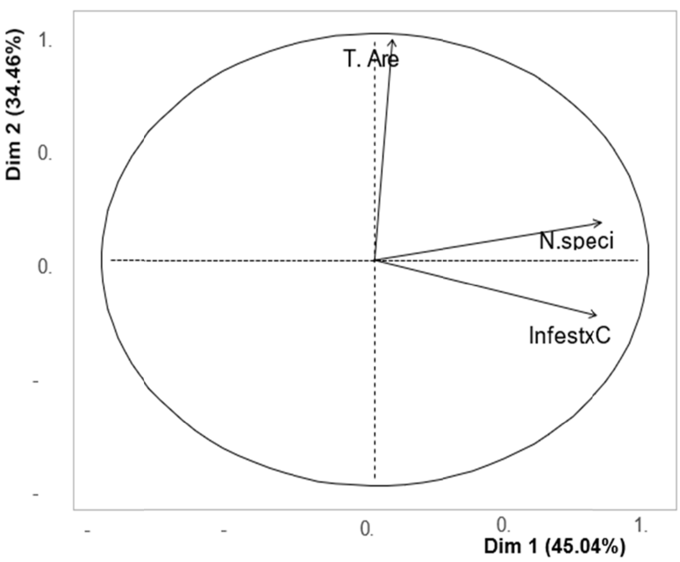


Figure 7. Principal component analysis carried out using data from the 2017/2018 growing season as reference, during the desiccation period with: InfestxC: Percentage infestation; N.Speci: number of species; T.Are: area size

In conclusion, the survey of weeds by aerial imagery was efficient for identifying, quantifying, and mapping weeds in commercial agricultural areas for management purposes. The high number of identified species of the same family, as well as the higher frequency of species observed in the ten-day periods before the starting of soy crop, indicated the dominance of some species. The number of species identified, the size of the area, and the sampling region were not correlated, because sites with low species diversity were more grouped than sites with high diversity.

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