A survey of problem weeds of sorghum and their management in two sorghum-producing districts of Zimbabwe

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Abstract: Sorghum is an important staple food crop in dry areas of Zimbabwe but yields are reduced due to inefficient weed management strategies that largely rely on hand weeding. A study to establish weeds associated with sorghum and their management was conducted in two sorghum-growing districts, Insiza and Chipinge, during the 2016/17 cropping season. Physical weed sampling in farmers’ fields was done to identify weeds infesting sorghum. A questionnaire was used to collect survey data from 80 respondents who were randomly selected. Physical weed sampling established that the dominant weeds that infested sorghum in the two districts were Amaranthus hybridus, Richardia scabra, Tagetes minuta, Striga asiatica, Commelina benghalensis, Eleusine indica, Datura stramonium and Panicum spp. Many of the weeds are broadleaf species, offering opportunity to harness sorghum allelopathy for weed control. Allelopathic compounds exuded by sorghum, such as...
sorgoleone, have been proven to largely suppress broadleaf weeds. There has been little change in the weed spectrum in sorghum when results of the current study are compared to benchmark national weed survey of arable lands of the smallholder farms of Zimbabwe conducted in 1988. This indicates possibility of high persistence of the soil seedbank. The majority of farmers in the two districts (85%) controlled weeds by hand weeding, indicating a very limited shift towards adopting alternative weed management technologies since 1990 when an inventory of weed science technological needs for communal farmers was compiled. Smallholder sorghum growers may need to broaden their weed management strategies in order to overcome some of the challenges that are associated with hand weeding.

Subjects: Agriculture & Environmental Sciences; Soil Sciences; Ecology - Environment Studies

Keywords: Smallholder farmer; sorghum; soil seedbank persistence; weed management technologies

1. Introduction
Sorghum [Sorghum bicolor (L.) Moench] is mainly an African cereal staple crop (Orr et al., 2016; Winchell et al., 2018) for millions of people in the semi-arid tropics of Africa and Asia (Organisation for Economic Cooperation and Development [OECD], 2017; Griebel et al., 2019). It ranks fifth in cereal production after maize, rice, wheat and barley (Boyles et al., 2018; FAOSTAT, 2017; Mundia et al., 2019). It can be cultivated as a fuel crop (Bergtold et al., 2017; OECD, 2010; United Nations Conference on Trade and Development [UNCTAD], 2016). The crop is normally cultivated under dryland conditions in marginal areas with high temperatures and low rainfall (Mobhaudhi et al., 2019; Mundia et al., 2019) because it can withstand wilting compared to maize (Food and Agriculture Organisation of the United Nations [FAO], International Crops Research Institute for the Semi-Arid Tropics [ICRISAT], 1996). It is mostly cultivated for household food security (Phiri et al., 2019). In eastern and southern Africa, cereal production is dominated by maize and sorghum comes second (Orr et al., 2016). The crop is mostly cultivated by smallholder farmers (Wortmann et al., 2009), sometimes on degraded soils (Smale et al., 2018) using low inputs (Haji & Tegegne, 2018; Mrema et al., 2016). The crop can thrive under low fertility environments (Kante et al., 2019). In Zimbabwe, sorghum is primarily cultivated in drought-prone areas in the agroecological Regions IV and V, which are classified as unsuitable for intensive cropping. Agroecological regions are land classes based on agricultural potential with respect to rainfall regime, soil quality and vegetation. These regions cover the Northern, North Eastern, Western and Southern marginal belts of Zimbabwe. Chipinge and Insiza are some of the sorghum growing districts of Zimbabwe that fall within Regions IV and V, and sorghum is a key food security crop in the two districts.

Weeds are a problem in crop production (Gage & Schwartz-Lazaro, 2019; Nwosisi et al., 2019; Westwood et al., 2018). They can reduce crop yields (Ball et al., 2019). They compete with crops for resources that include moisture, nutrients, space and light, and they can also harbor pests and diseases that infest crops (Brooke & McMaster, 2019). In a study testing the competitive effects of weed and crop density on weed biomass and crop yield in wheat, Wilson et al. (1995) established that increasing weed density where crop populations were low resulted in high crop yield losses. Sorghum grows slowly during the first few weeks after emergence (Ferrell et al., 2018). To prevent yield losses, weeds have to be controlled at critical periods during the crop growth cycle (Knezevic et al., 2002). It has been established through research that both light and heavy weed infestations during early growth can reduce grain sorghum yields, with high infestations causing yield losses of up to 20% (Barber et al., 2015).
Table 1. Weeds reported to be associated with sorghum

| Weed species | Common name | Family       | Reference                                      |
|--------------|-------------|--------------|------------------------------------------------|
| Abutilon theophrasti Medik | Velvetleaf | Malvaceae    | Ziska (2003)                                   |
| Acanthospermum hispidum DC. | Upright starbur | Asteraceae   | Centre for Agriculture and Bioscience International (CABI) (2019) |
| Amaranthus hybridus L. | Slim amaranth | Amaranthaceae | Tadesse, (2008)                               |
| Amaranthus retroflexus L. | Redroot amaranth | Amaranthaceae | Ziska (2003)                                   |
| Ageratum conyzoides L. | Tropical whiteweed | Asteraceae | Filho et al. (2014), Tadesse (2008) |
| Argemone Mexicana L. | Mexican pricklypoppy | Papaveraceae | Tadesse (2008)                                 |
| Bidens pilosa L. | Hairy beggarticks | Asteraceae | Filho et al. (2014), Tadesse (2008) |
| Chenopodium album L. | Lambsquarters | Chenopodiaceae | CABI (2019)                                   |
| Commelina benghalensis L. | Bengal dayflower | Commelinaceae | Filho et al. (2014), Tadesse (2008) |
| Convolvulus arvensis L. | Field bindweed | Convolvulaceae | Tadesse (2008)                                 |
| Corizya bonariensis (L.) Cranquist | Asthma weed | Asteraceae | Filho et al. (2014) |
| Cynodon dactylon (L.) Pers. | Bermudagrass | Poaceae | Tadesse (2008)                                 |
| Cynodon niemfuensis Vanderyst | African bermudagrass | Poaceae | Tadesse (2008)                                 |
| Cyperus esculentus L. | Yellow nutsedge | Cyperaceae | Tadesse (2008)                                 |
| Cyperus rotundus L. | Purple nutsedge | Cyperaceae | Tadesse (2008)                                 |
| Datura stramonium L. | Thorn apple | Solanaceae | Tadesse (2008)                                 |
| Digitaria sanguinalis (L.) Scop. | Hairy crabgrass | Poaceae | Filho et al. (2014) |
| Echinachloa crus-galli (L.) P. Beauv. | Barryyardgrass | Poaceae | Tadesse (2008)                                 |
| Eleusine indica (L.) Gaertn. | Goosegrass | Poaceae | Filho et al. (2014), Tadesse (2008) |
| Euphorbia hirta L. | Asthma plant | Euphorbiaceae | Tadesse (2008)                                 |
| Euphorbia heterophylla L. | Mexican fireplant | Euphorbiaceae | Filho et al. (2014) |
| Galinsoga parviflora Cav. | Gallant soldier | Asteraceae | Filho et al. (2014), Tadesse (2008) |
| Gynandropsis gynandra L. | Spiderwisp | Capparaceae | Tadesse (2008)                                 |
| Ipomoea spp. | Morning-glory | Convolvulaceae | CABI (2019)                                   |
| Nicandra physalodes (L.) Scop. | Apple of Peru | Solanaceae | Tadesse (2008)                                 |
| Oxalis spp | Pink garden sorrel | Oxalidaceae | Tadesse (2008)                                 |
| Panicum spp. | Panicgrass | Poaceae | Tadesse (2008)                                 |
| Portulaca oleracea L. | Little hogweed | Portulacaceae | Filho et al. (2014), Tadesse (2008) |
| Richardia brasiliensis | Mexican clover | Rubiaceae | Filho et al. (2014) |
| Rottboellia cochinchinensis (Lour.) W.D. Clayton | Itchgrass/Shamvagrass | Poaceae | Valverde (2003), Tadesse (2008) |
| Setaria spp. | Foxtail | Poaceae | Tadesse (2008)                                 |
| Striga asiatica (L.) Kuntze | Asiatic witchweed | Scrophulariaceae | Mrema et al. (2016), Tadesse (2008) |

(Continued)
Often, weeds are associated with particular crops. The reason for this is that each crop and associated management practices provide more or less specific conditions that act as filters (Belyea & Lancaster, 1999) offering different ecological niches for weeds (Meiss et al., 2010). Proper identification and management of weeds is critical for profitable crop production. Some of the weeds that have been identified in sorghum in studies that were conducted elsewhere are listed in Table 1.

The list of weeds that infest sorghum (Table 1), which is not exhaustive, comprises sedges, grasses and broadleaf weeds. A number of these weeds have developed resistance to herbicides targeting different sites of action (Table 2). This suggests that unless if they combine herbicides with other weed control tactics, smallholder farmers who use herbicides for weed control will have to contend with the challenge of herbicide resistance.

Weed communities of arable lands may evolve with time. Such changes may be caused by changes in crops being cultivated (Armengot et al., 2016) and changes in crop production practices (Hyvönen & Salonen, 2002), including tillage (Nichols et al., 2015). Changes in crop and fertilization (Kakabouki et al., 2015) may also cause differences in weed community composition that have management implications (Benaragama et al., 2019). Additionally, climate change can induce changes in the weed flora of arable ecosystems (Heeb et al., 2019; Peters et al., 2014; Scott

### Table 1. (Continued)

| Weed species                          | Common name     | Family          | Reference                                    |
|---------------------------------------|-----------------|-----------------|----------------------------------------------|
| Striga hermonthica (Delile) Benth.    | Purple witchweed| Scrophulariaceae| Mrema et al. (2016), Tadesse (2008)           |
| Tagetes minuta L.                     | Mexican marigold| Asteraceae      | Tadesse (2008)                               |
| Xanthium strumarium L.                | Giant cocklebur | Asteraceae      | Tadesse (2008)                               |

### Table 2. Reported herbicide resistance in weeds associated with sorghum

| Weed species                     | Site of action                                                                 |
|----------------------------------|-------------------------------------------------------------------------------|
| Echinochloa crus-galli           | EPSP synthase inhibitors, ALS inhibitors, Synthetic auxins, ACCase inhibitors, Cellulose inhibitors, Microtubule inhibitors, Photosystem II inhibitors, long chain fatty acid inhibitors, Lipid inhibitors |
| Abutilon theophrasti             | Photosystem II inhibitors                                                     |
| Galinsoga parviflora             | ALS inhibitors                                                                |
| Amaranthus hybridus              | EPSP synthase inhibitors, Synthetic auxins                                    |
| Bidens pilosa                    | ALS inhibitors, Photosystem II inhibitors, PSI electron diverter, EPSP synthase inhibitors |
| Cyperus esculentus               | ALS inhibitors                                                                |
| Chenopodium album                | Photosystem II inhibitors, ALS inhibitors                                     |
| Convolvulus arvensis             | PSI electron diverter                                                         |
| Datura stramonium                | Photosystem II inhibitors                                                     |
| Digitaria sanguinalis            | ACCase inhibitors                                                             |
| Eleusine indica                  | EPSP synthase inhibitors, PSI Electron Diverter, ACCase inhibitors, Glutamine synthase inhibitors, Microtubule Inhibitors, Photosystem II inhibitors, PPO inhibitors |
| Euphorbia heterophylla           | ALS inhibitors                                                                |
| Rottboellia cochinchinensis      | ACCase inhibitors, ALS inhibitors                                             |
| Xanthium strumarium              | Nucleic acid inhibitors, ALS inhibitors                                       |

Source: Adapted from Heap 2019.
et al., 2014), including alterations in weed biology (Ziska & Dukes, 2011). Resident species may also persist (Buhler et al., 1997; Mohammed & Denboba, 2020; Nikolić et al., 2020; Schwartz-Lazaro & Copes, 2019) due to intense selection pressure (Metcalfe et al., 2019). This makes it necessary for weed surveys to be regularly conducted so that any new weeds can be quickly identified so as to advise farmers on appropriate control measures against them.

Weed management is important for agricultural production (Westwood et al., 2018). The study by Chivinge (1990) on weed science technological needs for communal farmers of Zimbabwe, which was preceded by the first-ever national survey of weeds of arable lands in smallholder farms (Chivinge, 1988) might have been motivated by the realization that weed infestations and weed management strategies that are available and applicable to the smallholder farmers of Zimbabwe are unique. Typically, communal farming areas are characterised by poor rural indigenous households who practice subsistence agriculture, with surplus being sold at the markets (Proctor et al., 2000). While weed management in the large scale and commercial farming areas has been made comparatively easy by improved availability and affordability of resources, access to weed research information, access to extension services, as well as quicker adoption of modern weed management technologies, it has not been so in many communal farms of Zimbabwe, where, consequently, weeds continue to reduce crop productivity.

Weed management in most smallholder farms in developing countries is dominated by hand weeding (Chivinge, 1990; Gianessi, 2013; Sims et al., 2018), which is slow and cumbersome (Kumar et al., 2017; N’cho et al., 2019). In contrast, improvements in and adoption of improved weed management technologies have been made in other countries. Such technologies include precision weed management (Partel et al., 2019; Westwood et al., 2018), use of herbicides (Hale et al., 2019; Harker & O’Donovan, 2013), biotechnological approaches (Beckie et al., 2019; Duke, 2003) robotic weeder (Fennimore & Cutulle, 2019; Igawa et al., 2009; Lowenberg-DeBoer et al., 2019; Reiser et al., 2019; Sabanci & Aydin, 2017; Siemens, 2014; Slaughter et al., 2008), automated systems with sensor and computer technologies (Young et al., 2014), crop allelopathy (Alsosodawi et al., 2015; Macías et al., 2019; Trezzi et al., 2016; Uddin et al., 2014), flaming (Stepanovic et al., 2016) and other technologies providing site-specific weed control (Coleman et al., 2019). It is feared that in emerging economies and rural areas, weak technological infrastructure, high costs of technology, low levels of e-literacy and digital skills, weak regulatory framework and limited access to services mean these areas risk being left behind in the digitalization process (Trendov et al., 2019). Solutions for adopting new technologies for modern weed management technologies will, as argued by Korres et al. (2019), require a new weed management paradigm in modern agriculture, and this should be based on ecological principles and nonconventional weed management approaches. In relation to the particular conditions of Zimbabwe, however, not all of the modern weed management technologies listed above may be of significance. For example, precision agriculture is best applicable only for huge areas of fields covering dozens of hectares. In Zimbabwe, the average area of a sorghum field is only 0.4–2.0 ha. As for the use of herbicides, although they are still being promoted in some countries (Gianessi, 2013), the world trend is to reduce their application, and to apply them only if weeds exceed the economic threshold. Therefore in some cases, both hand weeding and mechanical weeding can be fully justified. Problem weeds that are currently infesting sorghum in Zimbabwe’s smallholder farms are not known. Little is also known about how farmers are managing these weeds. The objectives of the study were:

1. To identify major weeds associated with sorghum in the sorghum-growing districts of Insiza and Chipinge;
2. To identify the weed management methods used by sorghum growers in Insiza and Chipinge districts of Zimbabwe;
3. To identify and suggest best solutions for adopting modern weeding technologies.
2. Materials and methods

2.1. Study sites

The studies were conducted in Insiza (Latitude −19°46′59.99″S; Longitude 29° 11′ 60.00″) and Chipinge (Latitude −20° 11′ 17.99″ S; Longitude 32° 37′ 25.14″ E) districts.

Insiza district is in Matabeleland South Province of Zimbabwe. It covers 7 566 km² of land. The district falls under Natural Regions IV and V, and is therefore generally regarded as not suitable for crop production due to frequent drought spells and erratic rains. The average annual rainfall is 500 mm. The area is marginal for rainfed maize production (Bird et al., 2002), and drought-tolerant crops such as sorghum and millets are more suitable for the district. Cattle ranching and extensive farming are the recommended agricultural activities. Soils range from sandy loam to red clay. The average area grown to sorghum per household is 0.4 ha. The average yield per household is 0.5 tonnes ha⁻¹ and the district average annual yield is 1 415 tonnes. Sorghum is used for making thick porridge (locally known as isitshwala), making thin porridge, beer brewing, making non-alcoholic drink (mageu) and stock-feed.

Chipinge lies in southeastern Zimbabwe in Manicaland province. It is about 1134 m above sea level. The district experiences two types of climates; the highveld, which receives an average annual rainfall of 800–1 200 mm, and the lowveld, receiving an average of 450–650 mm. The highveld has predominantly sandy loam soils, while vertisols dominate the lowveld. The average land area dedicated to sorghum is between 1 and 2 ha per household. The farmers are mainly communal smallholder farmers who practise low-input sorghum production. They do not apply any form of fertiliser on the crop, except under-sponsored projects such as the FAO’s Conservation Agriculture. Sorghum is grown with little knowledge of the nutrient and pH status of the soil, and not surprisingly, the average sorghum yield in the district can be as low as 0.4 tonnes ha⁻¹. Other crops grown in the district are maize and cotton (Baudron et al., 2019).

The annual precipitation and temperature for the two districts for the 2016/17 season are shown in Figure 1.

2.2. Questionnaire survey sample selection and size

The sampling strategy that was used for the study is presented in Table 3.

A sample size of 90 for the study was determined following the procedure by Smith (2013). The sampling frames used for farmer selection were lists of sorghum producers obtained from the Department of Agriculture, Technical Services and Extension. In each district, 45 farmers were
Table 3. Summary of sampling strategy used

| District | No. of wards | Main sorghum growing wards | Randomly sampled wards | No. of households in sorghum growing wards | No. of growers in wards | Dominant producers in wards | Target sample/district |
|----------|--------------|-----------------------------|------------------------|------------------------------------------|------------------------|----------------------------|------------------------|
| Chipinge | 30           | 6                           | 3                      | 55000                                    | 3600                   | 1100                       | 45                     |
| Insiza   | 23           | 5                           | 3                      | 30400                                    | 7000                   | 2134                       | 45                     |
| Total    | 53           | 11                          | 6                      | 85400                                    | 10600                  | 3234                       | 90                     |
randomly selected with the guidance of district agricultural extension officers. However, due to the non-availability of some of the initially selected respondents, 40 farmers were interviewed per district, resulting in an effective total sample of 80 sorghum farmers. Prior to conducting the main survey, a pretest study was conducted in December 2016. This was done to improve validity in data collection and interpretation of findings (Goerman et al., 2019), and to detect errors and remove ambiguity of questions (Hilton, 2017; Hurst et al., 2015; Ikart, 2019). After pre-testing, the questionnaire was revised before conducting the main survey. Two enumerators were trained and they administered the 80 questionnaires under supervision. Prior to the surveys, each farmer completed a consent form, confirming that s/he was voluntarily participating in the survey. Farmers were promised confidentiality and that information obtained from them was going to be used for academic purposes only. To ensure quality data during fieldwork, all questionnaires were checked daily for inconsistencies which were rectified prior to departing the district.

2.3. Physical weed sampling in sorghum fields
Field surveys were conducted during the December 2016 to May 2017 sorghum cropping season in the two districts. Thirty farms in each of the two districts were randomly selected to examine weed density in sorghum. One sorghum field was sampled per farm. Where a farmer had more than one sorghum field, one field was randomly selected. Systematic sampling, as outlined in the procedure by Chivinge (1988), was done, with a few adjustments. Each field was divided diagonally and weeds were sampled after every 15 m following the diagonal lines. The starting point was 2 m from the edge of the field (Tibugari et al. unpublished data). In each field, four 40 cm × 40 cm steel quadrats were thrown along the diagonal lines and weeds in each quadrat were counted by species. The weed surveys were conducted three times; a week, 3 weeks, and 5 weeks after sorghum emergence. Sampling was conducted before farmers conducted weeding operations.

2.4. Data analysis
Data on major weeds found in sorghum fields and methods used to manage them were analysed using the Statistical Package for Social Sciences (IBM SPSS Statistics), Version 22. Results were presented in the form of simple descriptive statistics using tables. Field data on weed sampling were presented in the form of frequency tables. A comparison of the weed species that were recorded in the two districts was done in a tabular form. Field data for Insiza district were also compared with weeds that were found by Chivinge in 1988 in Matabeleland North and South Provinces, while field data for Chipinge district were compared with weeds that were found in Manicaland Province. This was done particularly to check if there had been new weeds in the smallholder farms since the 1988 weed survey.

3. Results and discussion

3.1. Questionnaire survey results
Farmers in both Insiza and Chipinge practiced hand hoeing, mechanical weeding and use of herbicides to control weeds (Table 4).

Results show that hand weeding is the major weed control method practiced in the two districts. Thirteen percent (13%) of the respondents reported that they mechanically controlled weeds in the sorghum crop and only 2% said they used herbicides. The result that hand weeding dominated

| Weed management method    | % of respondents |
|---------------------------|------------------|
| Hand weeding              | 85               |
| Mechanical control        | 13               |
| Herbicide application     | 2                |

Table 4. Weed management methods used in Insiza and Chipinge districts (N = 80)
in the study areas was not surprising. Hand weeding is considered less costly than the use of herbicides. There is also a public view that plant protection products are unhealthy and cause negative impacts on biodiversity and environment (European Parliamentary Research Service [EPRS], 2019). Hand weeding, which is slow and inefficient (Gianessi, 2013) consumes 75% of the farmer’s time during the weeding period (Chivering, 1990). Farmers in the two districts also controlled weeds mechanically. Mechanical weed control can be used together with hand weeding, thus reducing the labour required for hand weeding (Bárberi, 2003). The result that a few farmers used mechanical weed control suggests that there needs to be changes in cultural practices from broadcasting to row planting to provide opportunity for use of mechanical cultivation given that the farmers have the needed implements and draught animal power. Innovative extension approaches that allow farmers opportunity to compare technologies could also improve weed management by the smallholder farmers.

Farmers who controlled weeds by hand hoeing were asked how frequently they weeded in a season. The results are shown in Table 5.

The result that a large percentage of farmers weeded sorghum twice and thrice suggests that sorghum is an important food crop in the two districts and therefore farmers try to protect it from weeds so as to realize maximum yields. The result that a small percentage of farmers weeded only once suggests that some farmers tend to neglect sorghum by giving weeding priorities to other crops. Weeding once could also mean that there is less weed pressure under sorghum in these areas.

The few farmers who reported that they used herbicides had labour shortages for manual weeding and they applied the herbicide glyphosate (Roundup) once in a season. The use of the herbicide by communal farmers was not surprising. Globally, glyphosate has dominated the herbicide market (Dayan, 2019) and has therefore been the most widely used herbicide (Barker & Dayan, 2019; Davoren & Schiestl, 2018; Duke et al., 2018; Heap & Duke, 2017), partly because it is the only herbicide that targets 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) (Duke & Powles, 2008), has broad-spectrum herbicidal activity (International Agency for Research on Cancer [IARC], 2015); Vazquez-Garcia et al., 2020 and also partly because of its high biodegradation (Duke & Powles, 2008) and increase in the use of glyphosate-tolerant crops (Duke et al., 2018). The herbicide, which is non-selective (Beckie et al., 2020; Duke et al., 2018), is phloem mobile (Duke, 2018) and has been shown to be a genotoxic carcinogen (IARC, 2015; Center for Food Safety, 2015; Myers et al., 2016; Van Bruggen et al., 2018; Davoren & Schiestl, 2018; Agostini et al., 2019). It can be assumed that, due to its non-selective properties, in Insiza and Chipinge, smallholder farmers who use glyphosate either apply it as a pre-emergence application, or apply it selectively during crop growth by using shields which prevent the spray from getting in contact with the crop, as suggested by Ampong-Nyarko and De Datta (1991), Matthews (2000), and Lebot (2020). It is assumed that the smallholder farmers are aware of the potential health risks associated with the herbicide, that warrant its limited usage and use of appropriate protective clothing when conducting the mixing and spraying operations. It is also assumed that the smallholder farmers in Insiza and Chipinge districts are aware that weeds such as Amaranthus spp., Bidens pilosa and Eleusine indica have developed resistance to this herbicides, as research has already confirmed (Heap, 2020; Moss et al., 2019), and therefore reliance on glyphosate alone for their control may not be effective.

| Weeding frequency | % of respondents |
|-------------------|------------------|
| Once              | 14               |
| Twice             | 42               |
| Thrice            | 44               |

Table 5. Hand hoeing frequency
During focus group discussions it was revealed that farmers avoided using herbicides because calibration of herbicide application equipment required some degree of skill and literacy. Youths who could do the calibration were moving away from the family farms to urban areas in search for employment opportunities. It was also revealed that farmers had the perception that applying herbicides could damage the soil and contaminate water bodies. Some farmers were willing to use herbicides, but only if the chemicals were provided for free by government and development aid agencies. The result that low levels of literacy could affect herbicide usage suggests that smallholder farmers who want to use herbicides may require simplified training in herbicide application and safety. Poor access to herbicides by smallholder farmers can be a hindrance to their use. However, as argued by Lee and Thierfielder (2017) increased access has to be accompanied by responsible use.

3.2. Physical weed sampling in sorghum fields

Weed density measurements that were conducted in farmer fields established that a number of weeds infested sorghum (Table 6).

Table 6 shows that more weeds were recorded in Chipinge compared to Insiza. Chipinge district receives more rains and is generally wetter than Insiza, possibly allowing a wider range of weeds to flourish compared to Insiza, which is generally dry. Some weed species such as *Tagetes minuta*, *Commelina benghalensis*, *Amaranthus hybridus*, *Cleome monophylla*, *Richardia scabra*, *Cyperus spp.*, *Cochorus spp.*, *Datura stramonium*, *Setaria verticillata* and *Trubulus terrestris* were not recorded in farmer fields in Insiza. The result that more weeds were recorded in Chipinge than Insiza suggests that other factors such as rainfall, and not necessarily the type of crop grown, may influence the weed species that dominates a particular ecological niche.

Table 7 shows that the weed spectrum that was recorded by Chivinge in 1988 in both Insiza and Chipinge has not changed much. Tellier (2018) observes that one crucial role played by seed banks...
is to ensure that there is a decrease in population extinction rate. The result that there has been little change in the weed spectrum for the past 30 years suggests that the store of seeds of the weed species in the soil seedbank has persisted, rather than depleting. A likely cause of soil seedbank persistence could be linked to the use of the same weed management method; hand weeding, year after year to control weeds by the smallholder farmers. It is also likely that farmers in the two districts possibly do not control weeds that infest the sorghum crop towards crop maturity, leaving weeds to flower and set seeds, consequently allowing inputs into the soil seedbank through seed rain. Chivinge (1988) also made the observation that most small-scale non-commercial farmers abandon weeding once their crops have passed the flowering stage.

Of serious concern were two new problem weed species, namely *C. dactylon* and *Panicum* spp., that were recorded in Insiza, and four new weeds *Cochorus* spp., *Datura stramonium*, *Setaria*...
verticillata and Tribulus terrestris that were recorded in Chipinge. In the first national weed survey that was conducted by Chivinge in 1988, T. terrestris was recorded in Masvingo. Results reported here suggest that the weed has also spread to Manicaland Province.

4. Conclusions and recommendations

A diverse range of weeds that include Amaranthus hybridus, Richardia scabra, Tagetes minuta, Striga asiatica, Commelina benghalensis, Eleusine indica, Datura stramonium and Panicum spp. infested sorghum. Weed management in the smallholder sorghum growing districts is dominated by hand weeding. Gradual integration of existing weed management methods with modern weeding technologies will improve weed management in the smallholder farms.

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