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Weed Management in Zimbabwean Smallholder Conservation Agriculture Farming Sector

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Abstract

Weed management is one of the major constraints in the Zimbabwe smallholder farming sector contributing to smallholder poor yields, hence there is need to identify cropping systems that have potential to reduce weed pressure while improving crop yields. Conservation agriculture has been suggested as one of these farming systems. The implementation of CA three key principles reduces weed pressure even when the use of herbicides is minimised. Crops included in crop rotations, intercropping or relay cropping may have faster growth rate than weeds hence, have a comparative advantage over weeds. Maintenance of permanent soil cover through crop residues impedes weed germination thereby reducing weed population. Elimination of ploughing also reduces the chances of bringing buried weed seeds to the surface where their chances for germination are high. Hence, some seeds lose viability thus reducing weed density. Weed seeds accumulate at the surface, when allowed to set seed, increasing their exposure to predation resulting in reduction of weed density over time. The use of herbicides ensures that the fields are weed free as the season's progress thus ensuring better yields at the end of each growing season. Hence, weeds are reduced in CA systems over time despite the weeding option used.

Keywords: Conservation agriculture, minimum tillage, cover crops, rotations, herbicides

Introduction

The impacts of poor weed management practices have continued to worsen crop yield loss within the smallholder farming sector in southern Africa. This has left the majority of smallholder farmers food insecure where their average maize grain yields is as low as 0.8 tonnes ha⁻¹ (Baudron *et al.*, 2012). Traditionally, weed management has been handled via the use of conventional tillage

practices where the mould plough is the common tool used for land preparation (Colbach *et al.*, 2000). The mouldboard plough facilitates turning of the soils burying weeds and their seeds leaving the farmers' field weed free at the onset of the season. However, such weed management practices are ideal to farmers who have access to draft power that is necessary when using the mouldboard plough. Most of the resource limited smallholder farmers use hand hoes for land preparation, planting and weeding that is normally done three times per growing season (Siziba, 2008). However, hand hoe weeding is labour intensive (Mandumbu *et al.*, 2011) and

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labour availability is limited due rural to urban migration of most youths. Thus the smallholder farms are occupied by old farmers whom some of them have been affected by the HIV/AIDS pandemic disease that reduces their ability to weed three times and before yield losses are encountered. This has left more land abandoned due to weed infestation, especially on resources poor farms. Although the conventional tillage practises facilitates easy weed management practices at smallholder farming level, it has been reported to offer more detrimental effects on the farm. Conventional tillage practices increases soil loss in the fields (Alba *et al.*, 2006; Thierfelder and Wall, 2009; Zhang *et al.*, 2003). This reduces the productivity of the plots since most fertile soils are washed away by water runoff (Thierfelder and Wall, 2012; Thierfelder and Wall, 2009).

Also, conventional ploughing reduces soil moisture retention and crops are affected by moisture stress that are commonly experienced during the growing season which results in yield decrease at the end of the season (Thierfelder and Wall, 2010). Due to increasing worries about low yields in smallholder farming sector, most researchers became interested in promoting more sustainable agriculture systems that will enable yield increase and safeguarding the soil quality. One of the proposed farming systems is conservation agriculture (CA) which is expected to promote more precise use of land, vegetation and water resources.

It is defined as a farming system that is based on three principles namely (a) minimum soil disturbance, (b) diverse crop rotations and (c) maintenance of a permanent soil cover through crop residues (Kassam *et al.*, 2009; FAO, 2010). It is generally gaining acceptance in Zimbabwe smallholder farming and most of the farmers have heard or practiced CA. It has been reported to increase yields, promote moisture retention by reducing runoff, reduce soil loss and increase soil organic matter content (FAO, 2001; FAO, 2002; Hobbs, 2007; Johansen *et al.*, 2012; Kassam *et al.*, 2012; Kassam *et al.*, 2009).

Although it is reported to have more benefits over conventional ploughing, it requires proper or well-planned weed management practices to overcome an expected increase in perennial weed species. A suggested increase in perennial weed species (Gan *et al.*, 2008) increases the complexity of weed management under CA; hence the first years of adopting CA may require the use of herbicides (Wall, 2007). Some researchers have observed a decrease in weed density during the growing season via use of herbicides and even in hand hoe weeding only (Muoni *et al.*, 2013). This suggests that CA has potential to decrease weeding problems over time even when manual weeding is the available weeding option by adopting all three CA principles and avoid neglecting any one of the principles.

CA principles on weed management

Minimum soil disturbance

Elimination of soil inversion enables all the buried weed seeds to remain dormant for a long time and reduces their chances of germinating. Minimum soil disturbance ensures that all weed seeds that are buried within depths of 10cm or more are not exposed to the surface where there are conducive environments for germination since the soil is not disturbed to such depths (Forcella and Lindstrom, 1988). The weed seed bank is likely to be depleted with minimum soil disturbed since weed seed that is on the soil surface is not buried hence, exposing them to predation by birds and other macro fauna (Baral, 2012). It has been reported that in reduced tillage systems there tends to be a shift in the weed spectrum and annual weed species become the dominant ones and hence making weeding easier since these are easier to eradicate compared to perennial ones (Muoni *et al.*, 2013). Annual weeds germinate in one season so if controlled timely, their seed bank is depleted quickly over the seasons.

However, with a shift from conventional to reduced-tillage practises, there is a shift in weed spectrum and this leads to difficulties in the handling of weeds during the first years of

CA. A knowledgeable understanding of the new weed species is required for them to be controlled much more easily of which most smallholder farmers lack this (Derpsch, 2008). Also, with reduced tillage, weed species that produce through rhizomes e.g. *Cynodon dactylon* become more difficult to control since the underneath rhizomes are not disturbed (Vogel, 1994b). This calls for the use of herbicides e.g. atrazine which may be unaffordable to some smallholder farmers or may not be used in some crops like soybean restricting possible desirable crop rotations.

Diverse crop rotations and plant associations

Crop rotations have been reported to play an important role in the eradication of weeds in CA systems. There are some weeds that are crop specific e.g. *Striga hermonthica* (Del.) which is stimulated to germinate by certain chemical compounds found in root exudates produced by cereals (Kanampiu *et al.*, 2002). The witch weed can lead to yield losses of up to 100 % in cereal systems and in Africa losses of up to approximately US\$40 million have been reported in maize and sorghum-based systems (Kanampiu *et al.*, 2002). *Desmodium uncinatum* is a legume that may be rotated with maize and this legume produces a chemical that stimulates suicidal germination of *S. hermonthica* but *S. hermonthica* will not be able to attach to the roots of this legume to siphon nutrients and hence will eventually die off and with time, the *Striga* seed bank is depleted (Khan *et al.*, 2010). There are some leguminous cover crops that may be incorporated into rotations and these produce allelochemicals that have live allelopathic effects on some weed species e.g. *Crotalaria juncea* (Skinner *et al.*, 2012; Moyer, 2008). In the presence of these cover crops, some weed seeds are unable to germinate or die at early stages due to competition for resources before they reproduce seed and so depleting the weed seed bank leading to a gradual decline in weed numbers (Norsworthy *et al.*, 2011; Fisk *et al.*, 2001). Sunflower has been reported to have an allelopathic effect to quite a number of weeds species and so its involvement in cropping

systems ensures a decrease in weed problems (Leather, 1987). In addition to their ability to suppress weeds, leguminous cover crops may also contribute significantly to the nitrogen in cropping systems (Thierfelder *et al.*, 2012). However, rotations with these edible and non-edible legumes may a challenge for some smallholder farmers due to unavailability of ready market for the legume seed (Thierfelder *et al.*, 2012) and also due to limited access to arable land and hence find it difficult to substitute staple crops with these legumes.

Maintenance of a permanent soil covers through crop residues

Permanent soil cover is attained by retention of crop residues on the soil surface. The residue maybe of the previous crop or may be imported into the field. When spread on the surface, crop residues offer a smothering effect on the weeds and hence, hinder their growth leading to their death (Sasa, 2009). In some cases, weed seeds may germinate but due to the presence of the layer of residues, they may fail to emerge but if the weeds manage to emerge, they may be shaded from light by the crop residue and will eventually die before they reproduce leading to reduced number of weeds over the seasons (Chauhan and Abugho, 2013; Moyer, 2008). Runzika *et al.* (2013) found out that some cover crop residue e.g. jack bean (*Canavalia ensiformis*) have functional allelopathic effects on weeds like the *Eleusine indica*, *Bidens pilosa* among others so their involvement in cropping systems reduces these weed species. The presence of crop residues has been reported to improve macro- and microbial activity in the soil and so this also improves the predation of weed seeds by some microorganisms that are found in the soil leading to reduced number of weeds seed and in turn reduced number of weeds (Kremer, 2000). However, a study by Vogel (1994a) revealed that the presence of crop residues may block herbicides from reaching the weeds therefore reducing their efficiency.

Chemicals and manual weed management systems

The most effective and time-efficient weed control method is the chemical weed control (Chhokar *et al.*, 2007). Under this strategy any technique which involves the use of herbicides is summarized as chemical weed control (Boydston *et al.*, 2012). The use of herbicides is effective and ensures a decrease in weed density over time (Muoni *et al.*, 2013). CA is associated with increased weed problems during the early years of adoption thus herbicides has been highly recommended for weed control. However, great care should be taken when handling herbicides to prevent contaminations of the sprayer. This is achieved by wearing protective clothing when spraying and destroying the empty containers after use to avoid contamination of water bodies. The exponential growth of CA in Brazil and Argentina was mainly due to the availability of more effective and affordable herbicides in their countries especially glyphosate and paraquat (Bolliger *et al.*, 2006).

To date, smallholder farmers in southern Africa use herbicides only in Malawi, where it has become a common practice due to the influence of Sasakawa Global 2000 (Ito *et al.*, 2007). In other areas herbicides slowly become more known as an economic way of weed control (Rugare and Mabasa, 2013). Potential herbicides for CA available in Zimbabwe include atrazine, glyphosate, metolachlor and paraquat among others.

Atrazine

Atrazine is a selective herbicide with an active ingredient found in many products that control a wide range of broadleaved weeds and some few grass species. It can therefore, be used in maize production. It is a pre-emergent herbicide that can be applied early, post, alone or in combination with other compatible herbicides (Williams *et al.*, 2011). This enables farmers to combine it with other herbicides thus widen the weed spectrum controlled. Its active ingredient is s-triazines [2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine], and it is widely used in most parts

of the world (Williams *et al.*, 2010). Atrazine is a photosynthetic inhibitor which blocks electron transport between the primary Q_A and secondary acceptor Q_B plastoquinones in photo system II in the chloroplasts and has long lasting soil activity, which enables it to control late emerging weeds (Baker *et al.*, 2007). Depending on soil texture and amount of irrigation, the herbicide half-life ranges from one week to more than a year (Hang *et al.*, 2003). The herbicide can be carried over to the next season but the carry-over is largely dependent on climatic and edaphic conditions (Helling *et al.*, 1988).

The effects of the CA system on atrazine carry-over are not yet fully understood but the herbicide carry over to the next season may be reduced by increased biological activity under conservation agriculture. Retention of residues and minimum soil movement induces biological activity with strains possessing atrazine chlorohydrolase, *atz A* (Eapen *et al.*, 2007) and related amidohydrolase enzymes, *trzN* (Houot *et al.*, 2000) which may enhance atrazine degradation in soil. During metabolism, atrazine is dechlorinated and additional enzymatic hydrolytic transformations end in atrazine-ring cleavage, mineralization, and successive release of ammonium (Wackett *et al.*, 2002). Nitrogen released from atrazine metabolism serves as a nitrogen source for atrazine-degrading bacteria. Thus, using atrazine under CA can be very efficient since it will be available for almost a third of the season to control emerging weeds. Nevertheless, the use of atrazine has been banned in Europe as it leaches to groundwater which raised concern on the safety of life (Helling *et al.*, 1988). However, the current cumulative risk assessment of atrazine by the U.S Environment Protection Agency has shown no evidence on the negative effects of the traces of the herbicide on human life hence; the herbicide was reregistered in 2006 in Europe (Williams *et al.*, 2010; Williams *et al.*, 2011).

Glyphosate

Glyphosate with its active ingredient [N-(phosphonomethyl) glycine], is a non-

selective systemic herbicide applied post emergent to green tissues. The herbicide inhibits the activity of the enzyme 5-enolpyruvylshikimate-3-phosphatesynthase (EPSPS synthase) where the herbicide molecule binds to the EPSPS synthase (Franz *et al.*, 2009). The binding of the herbicide alters the shape of the enzyme thereby disturbing the normal function of the enzyme which results in the control of living plants. Glyphosate is an effective herbicide on perennial grasses but supplementary weeding is necessary because it lacks residual activity to control newly emerging weeds (Chikoye *et al.*, 2010). Glyphosate resistant crops like roundup-ready soybean and maize (i.e. genetically modified organisms (GMOs) can be grown to reduce supplementary weeding with hoes (Balkcom *et al.*, 2011). Round-up ready maize supports a full cover spray of glyphosate even after the crop has emerged without any damage to the crop. The herbicide has been reported to have low-mammalian toxicity (Riley *et al.*, 2001) thus making the herbicide a good option for CA.

The introduction of glyphosate augmented the widespread adoption of CA in the Americas due to reduced weeding and operation costs (Derpsch, 2008; FAO, 2001). Glyphosate replaced the need for tillage practices to reduce weed pressure at the onset of the season (Yang *et al.*, 2008) (Yang *et al.*, 2008). Hence, the use of glyphosate as a weed control strategy is an effective measure to reduce weed pressure at the onset of cropping season and ensures less contamination of groundwater and the environment (Stewart *et al.*, 2011). It can be applied at seeding with a knapsack sprayer and during the growing season if a weed wipe is used (Rugare, 2009). This helps to control newly emerging weed shoots during the season. However, it has been reported that the herbicides should not be used on soils with a sand content greater than 90% (Thierfelder, personal communication). The herbicide is deactivated through binding on clay particles hence, the herbicide remains active in soils where not enough clay or organic matter is present, which may have

significant inhibitory effects on plant emergence.

Though the herbicide is effective, some weed species have been reported to be resistant to glyphosate and these includes *Conyza bonariensis*, *Digitaria insularis* and *Lolium rigidum* among other weed species (Johnson *et al.*, 2009). To reduce such risks of weeds developing resistance, integrated weed management practices have been recommended by many researchers (Deytieux *et al.*, 2012; Mandumbu *et al.*, 2011; Mézière *et al.*, 2013; Pardo *et al.*, 2010; Vogel, 1994a).

Metolachlor

Metolachlor is a chloroacetamide herbicide (active ingredient: 2-chloro-N-(2-ethyl-6-methylphenyl)-N-2-methoxy-1-methylethyl), which belongs to the acetamide family. It is applied as pre-emergent herbicide in maize, soybean, sorghum, potatoes amongst other crops (Rivard, 2003). It acts as a growth inhibitor that suppresses the synthesis of chlorophyll, fatty acids, proteins and lipids in both grasses and broadleaved weeds and the herbicide can suppress *Striga* (Kabambe *et al.*, 2008). The product is a short residual herbicide that can be mixed with atrazine and glyphosate. The herbicide half-life ranges from 7 to 292 days depending on soil type (Kabambe *et al.*, 2008).

Paraquat

Paraquat, [1, 1'-dimethyl-4, 4'-bipyridinium], is a non-selective contact herbicide capable to suppress both perennial grasses and broadleaved weeds. It is a post emergence herbicide, a photosynthetic inhibitor, which is applied after emergence of weeds. Great care should be taken to avoid spraying the main crop with paraquat (Croplife, 2006). The herbicide should be applied to green tissue, where it intercepts electrons from photosynthesis and transfers energy to free radicals and damages the cell membrane that permits leaching of cell contents to intercellular spaces (Dodge and Harris 1970). Though the herbicide may be ideal in CA systems, it works best when the target plants are already stressed (Baker *et al.*, 2007). It is

bound to soil particles and remains bound for a long time but it can be desorbed again and become biologically active (Rytwo *et al.*, 2010).

Though paraquat is not restricted in many countries, the herbicide is the most acutely toxic herbicide that may cause death if farmers do not wear enough protective clothing as well as use leaking knapsack sprayers (Rytwo *et al.*, 2010). Some countries have restricted the use of paraquat mainly for health reasons.

Manual weeding

Another common method in smallholder farming is mechanical weed control. This method involves killing or suppressing weeds through physical beating or disruption. However, successful control depends on the life cycle of the target weed species. Examples of techniques include hand pulling and hand hoeing. The use of hand hoes in small-scale farming is a common practice in Zimbabwe (Siziba, 2008) but it is labour intensive and generally affected by the health and mood of the farmer and also the availability of labour (Steiner and Twomlow, 2003).

Conclusions

This paper has given an account of different weed management strategies under CA. Minimum soil disturbance reduce bringing buried weed seeds to the surface where conditions are favourable for germination hence their chances of germination are low reducing weed densities over seasons. On the other hand, there is accumulation of weed seeds at the soil surface where they are likely to germinate within one season and if timely weeding is practised the weed seed bank is likely to be depleted over shorter periods of time compared to conventional systems. Weed seed are exposed to predation and are damaged making them fail to germinate when they are left on the surface and hence depleting the weed seed banks. Retention of residues promotes increased macro- and microbial activity which increases organic

matter and hence improved crop growth giving them a competitive advantage over weeds. Retention of crop residues also promotes build up fungi and bacteria which facilitate fast decomposition of weed seeds before they germinate and hence over time the weed seed bank is depleted making weed management easier over time. Crop rotations and/or crop interactions, if designed properly, are capable of reducing weeds to manageable levels. The involvement of allelopathic crops such as sunflower in cropping systems facilitates weed suppression that enables decrease in weeding pressure. Crop rotations with leguminous cover crops that have a vigorous growth ensure the smothering of weeds and at the same time contributing to nitrogen in cropping systems and hence, eventual death of weeds and crop yield improvement. The use of herbicides also facilitates the reduction of weed density during the cropping season and continuous application reduces weeding pressure over seasons. However, timely and correct application of herbicides determines the success of reducing weed density and avoiding crop yield loss. Herbicides can be combined with manual weeding that facilitate further depletion of the weed seed bank over time and controls all the weeds that may have escaped initial herbicide application through impeding by crop residues. Although weed management is complex within the first years of CA adoption, CA cropping systems has potential to reduce weed pressure over time if the three principles are timely implemented.

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