Literature Review

CONTROL AND MANAGEMENT OF VOLUNTEER POTATO PLANTS

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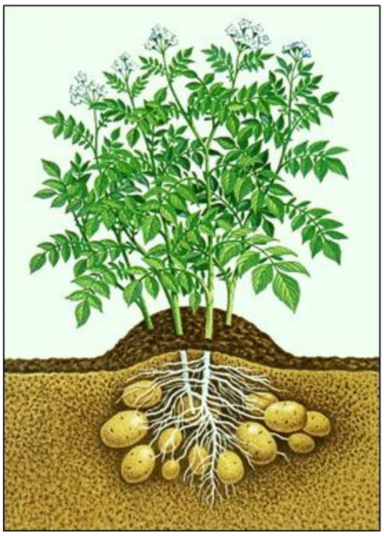

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CONTROL AND MANAGEMENT OF VOLUNTEER POTATO PLANTS

1. Introduction

Large numbers of potato tubers, as many as 460 000 tubers ha^{-1}, remain in the land after harvesting of commercial potato plantings using mechanical potato harvesters (Lumkes, 1974; Lutman, 1977; Perombelon, 1975; Steiner et al., 2005; Boydston et al., 2006). These tubers will survive if the winter temperatures do not regularly drop below -1.5°C and will sprout and start growing during the following season. These volunter potato plants cause a serious weed problem, not only in table, processing and seed potato lands, but also in the rotation crops that follow the potatoes (Smid & Hiller, 1981; Boydston et al., 2006).

These volunteer potato plants are difficult to control due to the large carbohydrate reserves that are found in the large seed pieces, as well as the ability of the tubers to resprout after the application of various control methods (Boydston & Seymore, 2002; Williams & Boydston, 2002). A further factor that hinders control in the relative depth from which sprouts can emerge, and the fact that these tubers are buried far deeper than the seeds of the majority of annual weeds (Wright & Bishop, 1981; Thomas, 1983).

Not only are these volunteer plants a source of competition with the crop plants for water, nutrients and light, but they are also a source of harmful organisms such as diseases, nematodes and insects, which can reduce the beneficiall effects of rotations systems (Wright & Bishop, 1981; Thomas, 1983; Steiner et al., 2005). These pests and diseases can also be carried across to nearby potato fields and cause major problems, particularly where the lands are used to produce seed potatoes, as these contaminants can make the crop useless for seed. It it, therefore, imperative that these plants be controlled as quickly as possible to avoid these situations.

Unfortunately it is very difficult to control volunteer potato plants. Although methods have been developed to manage volunteer potato populations there is not yet a single method that is suitable to reduce the numbers sufficiently to prevent competition with crop plants, while still fitting in well with the various rotation systems that are used. The general view is that it is better to follow a holistic management approach to deal with the problem.

The objective of this study is to provide information about the methods that are presently being used for the control and/or management of volunteer potato plants.

2. Importance of control / management of volunteer potato plants

The presence of volunteer potatoes and the problems caused by this phenomenon has been a headache for the agricultural community for almost 80 years (Bonde, 1942; Fernow, 1959) and is the subject of continual research (Boydston en Seymour, 2013).

During 1932 it was noticed that bacterial wilt was carried over by volunteer potatoes to the next following year's potato crop. Hereafter farmers were cautioned not to plant potatoes in the same field for two years running and to therefore, to practise crop rotation. The first use of chemicals to control volunteer potatoes was recorded in 1959 when amitrol (3-amino-1,2,4-triazol) was used experimentally to combat this problem (Fernrow, 1959).

Volunteer potatoes affect crop production in three ways, i.e. competition with the following crop, transference of pests and diseases to the next crop, and the contamination of the succeeding crop during crop rotation.

2.1 Competition

One of the critical factors in the success of a crop is free access to nutrients, water, physical space and sunlight. With commercial planting the physical spacing of the individual plants are strictly planned and monitored. Each plant then has equal access to the available nutrients, water and sun. This leads to even germination, growth and yield. However, if the lands are not cleared of other plants (weeds) before and during the growth season, these weeds can compete with the crop for nutrients, water and sun light. This especially becomes a problem when the weed emerges just before or at the same time as the crop. The crop is then in direct competition with the seed and the yield can be adversely affected. The common definition of a weed is any plant growing where it is not wanted. For the purpose of this writing, volunteer potatoes are seen and described as weeds.

The main reason for the implementation of crop rotation is the decrease of potential plant pathogenic organisms. The theory behind this is that the disease causing organism or its vector is left without a host during the next season and they cannot therefore, increase of even retain their numbers. The follow-up crop must not be susceptible for any diseases that occurred in the previous crop and that may have survived in the soil or on organic material. Although this practice may prevent the carry over of potato diseases to resistant crop the following season, it does not deal with the physical competition of volunteer potatoes. Many of these tubers will give rise to volunteer plants the next season, which will compete with crops and lead to lower yields. The more volunteers the larger the effect on the yield of the crop would be.

For table and processed potatoes a planting density of 30 000 to 60 000 seed tubers are planted per hectare, and for seed potatoes, 60 000 to 120 000 seed tubers are used.

Up until 2007 there has not been a world wide census of the amount of potato tubers that are left left behind, and it is therefore difficult to estimate the exact effect of this phenomenon. Some of the viable tubers are so small in size that they may not be identified and published number may be a serious under estimation (Askew & Struik, 2007). Freezing conditions in the northern hemisphere plays an important role in the control of these tubers, but is not relevant in South Africa as a control measure.

Steiner *et al.* (2005) reported that between 180 000 and 400 000 potato tubers can be left behind on a hectare after harvest. Maize planted on these lands can be subjected to a yield loss of between 23% and 62% if the volunteer plants are not controlled, even if it is one of the crops that can best withstand weed potatoes competition. Onion and carrot yield can be decreased by as much as 90% if volunteer potatoes are not controlled. The presence of volunteer potatoes in onion crops affects both the size and the yield by 27% to 82% depending on the time of exposure of the crop to the weeds. Control of weed in commercial carrots is problematic due to the sensitivity of carrots and the lack of registered herbicides for this crop (Williams and Boydston, 2006). The narrow row width makes mechanical weeding difficult and hoeing is very expensive. Even at a low infestation rate, up to 100% of the carrot crop can be lost is the potato plants are not removed. Yields of bean, sugar beet, other legumes, mint and wheat are also negatively affected. It is critical to pay attention to an integrated weed control program as no single method has proven successful (Williams *et al.,* 2005; 2007). In South Africa it is estimated that approximately 20 – 25% of the mass of tubers planted is left on the field after harvesting.

2.2 Transfer of pests and diseases

During harvest, most of the crop is removed from the land and the plant debris is ploughed into the soil to break down as green manure. During the growing season weed are removed and theoretically no host plant are left on the field to house disease causing organisms or their vectors. The potato tuber is a living organism and can thus protect spores or eggs of diseases and their vectors till the next season. Even if the disease is not a problem on the follow-up crop, the long time that volunteer potatoes can survive and reproduce in the soil, can lead to the next potato crop being seriously infected with a pest.

Such pests can not only have a direct effect on yield, but cause problems during storage after harvest. The potato tuber worm (*Phthorimaea operculella* Zeller) is described as a significant problem on potatoes before harvest and during storage. The infection may not be visible during harvest and still cause serious problem during storage. It can survive as an egg, larvae or pupa on tuber left behind in the soil (Rodon, 2010) and is seen as a serious problem in South Africa (Watmough *et al.,* 1973).

Potato blight, caused by a variety of *Phytophthora infestans* (Mont) species was the probable cause of the Irish famine in the 1800s. This is still a devastating disease in potatoes and have be found to survive in volunteer tubers in the soil under a variety of temperatures, even under freezing conditions that killed other pathogens (Gigot *et al*., 2009). This fungus is of great economic importance in South Africa on potatoes and tomatoes (McLeod *et al.,* 2001).

Glyphosate is systemic herbicide that can be used on crops containing the Roundup Ready® gene which protects the plant from damage by this herbicide. It can therefore be used to eradicate weeds without damage to the crop plant. This was tested and found to not only decrease the amount of root knot nematodes in RR sugar beet lands, but also reduce the amount and size of daughter tubers of volunteer potatoes (Dewar *et al*., 2000). Although sugar beet is not commercially produced in South Africa, glyphosate should be kept in mind in future research.

In America sugar beet is often planted in rotatation after potatoes and the emergence of volunteer potato plants has serious effects on the yield of this crop. Due to the precence of the Roundup Ready® gene in the beet, glyphosate could be used in order to eradicate emerging potato plants (Felix and Ishida, 2008). The effect on sugar beet yield and the amount of potatoes harvested from the volunteer varied according to the timing of glyphosate application and the repetition of the application. Exudates from volunteer potato roots stimulate the germination of potato cyst nematodes eggs. Using glyphosate as a herbicide on these weeds, deprives the nematode eggs of the germination stimulus and leads to significant reductions in the numbers of these pests (Dewar *et al.,* 2000).

Volunteer potatoes not only potentially carry diseases, but can act as host for insect vectors, especially aphids that commonly carry plant pathogenic viruses (Thomas & Smith, 1983). Potato virus X carried on volunteer potatoes that were left to grow, increased the appearance of the disease by more than 12% by the end of the season. The yield of any follow-up crop that is susceptible to this virus will be devastated unless such tubers/plants are destroyed before or as they emerge (Thomas & Smith, 1983). Apids are also serious pests on potatoes in South Africa, carrying a variety of virusses from volunteer plants to the follow-up crops (Krüger & Robertson, 2008). Not only can these be carried over to the follow-up crop, but also to other potato plantings in the vicinity.

The organism that causes bacterial wilt on potatoes *(Ralstonia solanacearum*) is suppose to be totally eradicated when the host plant is removed from the land, therefore, any remaining organic material such as tuber, or pieces of tuber that remain will constitute a bacterial sink and potential cause of reinfections in a susceptible follow-up crop (van Elsas *et al*., 2000). These include tomato, pepper, eggplant, banana, groundnut, olive, ginger, beans and beet, Eucalyptus and cultivated geraniums, as well as davana (*Artemisia pallens* Wall.) and coleus (*Coleus forskohlii* (Wild.) Briq.), both which are important crops in the medicinal and aromatic oil industries in India (Genin, 2010). Though few of these are cultivated as follow-up crops to potatoes, contact with infected tools/implements can spread the disease.

2.3 Contamination of succeeding crops

In order to protect the consumer and retain a high level of uniformity, it is critical to deliver a product that is pure and free from any contaminants. This includes soil particles as well as foreign seeds and weed plant residue. Contamination can cause problems during processing, packaging and especially during classification which can have a direct effect on the price.

A new problem which accompanies the emergence of genetically modified (GM) plants is the possible spread of transgenic material to other plant through pollen or seed. Pollen can be spread by wind and seeds through tools and implements to neighbouring fields or even next door farms. Experiments have found fewer GM than non GM volunteer potatoes at low winter temperatures, but even a few emerging GM volunteer potatoes can pose a danger (Kim *et al*., 2010).

Peas are mechanically harvested and the presence of potato leaves and seed berries can easily contaminate the product during harvest. As peas for the canning or freezing industry have to be completely clean, the entire harvest can be rejected and lost if contaminated by volunteer potatoes (Rahman, 1980; Steiner *et al*., 2005). The potato seed berries are also toxic and lead to health problems if included in other processed foodstuffs such as peas, beans and carrots (Bond *et al.*, 2007).

Commercial seed potatoes are certified for purity before distribution to potato producers and contamination with tubers from volunteer potatoes of a different cultivar can lead to the production of a mixed variety. Although this is not critical in the fresh or processing market, it will lead to the rejection of the harvest for seed production (Steiner *et al.*, 2005).

3. Biology of the volunteer potato plant

The potato plant (*Solanum tuberosum* L.) is a herbaceous annual species that is propagated through either true seed or vegetatively via the swollen underground stem tubers. Seed is normally used in breeding programmes, while tubers are used to establish all commercial plantings. Volunteer potato plants in South Africa, as in the USA, originate almost exclusively from tubers rather than from true seed.

3.1 Survival and persistence in the soil

Although certain potato cultivars can produce viable "true" seed, these are only used for research and breeding, never for cultivation. In order to preserve the purity of a line, only vegetative reproduction is used in planting. In most cases a specific cultivar seed potato is obtained with the specific aim of producing a selected product; chips, crisps, table or processed potatoes.

Although there are few peer reviewed article published in South Africa on the time that volunteer potatoes can survive in the soil, research in the northern hemisphere has shown that this weed can continue growing and producing daughter tuber for more than 20 years. South African research has indicated that no crops sensitive to silver scab (*Helmithosporium solani* Dun. and Mont.) and black spot (*Colletotrichum coccodes* Wallr.) should be planted within five to six years after a potato crop (Denner, 2012).

Volunteer potatoes are the result of harvesting methods of commercial potato planting, and the fact that potatoes keeps on producing a magnitude of small tuber which are not picked up by commercial harvesters, or lost in the process of loading and transport of the harvest. Estimations of the amount of tubers left on top of the soil or up to 20 cm underground varies widely throughout production areas. Rahman (1980) reports numbers of 367 000 tuber per hectare, this translates to 10% of the potential yield or one to four tons per hectare. This represents a total potential population of 2 to 30 volunteer potato plants m^{-2} (2 000 to 30 000 plants ha^{-1}). The persistence of viable daughter tubers as small as one centimetre in diameter is an exacerbating factor. Contact herbicides only kill the above ground growth, leaving the tuber to regerminate. Systemic glyphosate has been proven to migrate to the tubers and stop further growth, but has to be used with care.

In many parts of the northern hemisphere winter temperatures can drop below freezing in winter. Tubers on top of the soil and up to 10 cm below the surface are killed by temperatures below -2°C, but the deeper tubers are insulated by the soil. These findings are influenced by snowfall, stubble and soil cover crops which all serve as insulation. Cultivation of the soil can also push tuber deeper underground, protecting them against freezing (Boydston et al., 2006). These conditions play a very small role in South Africa, as very few potato producing areas are subject to such low temperatures for an extended period of time, and so cannot be seen as a preventative measure.

True potato seed can stay viable in the soil for up to seven years. One berry can contain up to 300 seeds and volunteer potatoes that produce berries are an important factor in survival of volunteer potatoes if control is not carried out prior to flowering taking place, much the same as is done in controlling any other weed. Seedlings that emerge in June in the northern hemisphere (around December in the southern hemisphere) can still produce small tubers that can survive in the soil (Bond *et al*., 2007).

3.2 Sprouting and emergence

When no follow-up crop is produced and no cultivation is carried out on the previous year's potato field, the volunteer potatoes are reliant on soil temperature, depth of the tubers and rainfall for emergence. Due to the variation in tuber depth, emergence occurs over a period of two to three months or even longer and control measures will have to be implemented repeatedly (Rahman, 1980). Each potato cultivar has its own accumulated heat units for eye and sprout development and if there is enough moisture available, sprouts will form. Until the first green material emerges above the soil and start photosynthesis, the growth of the plant is dependent on the stored nutrients in the tuber. In a seed potato there are usually enough nutrients for 30 days of growth. The smaller the tuber and the deeper it is buried in the soil, the smaller the chance that the stem will emerge. It normally takes between 10 and 20 days for the above ground parts to produce enough photosynthates to become independent of the tuber. At this stage the plant is most sensitive to herbicides as few if any daughter tubers would have been formed (Colquhoun, 2006).

3.3 Growth and development

As soon as the sprout breaks through the soil surface, leaves and branches starts forming on the nodes. The plant is now reliant on sunlight for photosynthesis and the underground sprouts starts forming stolons. The optimum temperature for the successful formation of above ground parts and stolon development is 25°C. Lower temperatures can inhibit growth and initiate formation of tubers (Steyn, 1999).

During soil cultivation for the succeeding crop the soil is disturbed and tubers not damaged by this treatment will start to germinate and be well established by the time the follow-up crop is planted. Favourable weather conditions in terms of rain and temperature will enhance potato growth (Steiner *et al.*, 2005).

3.4 Seed and tuber production

Tuber formation is initialised through hormones, the production of more photosynthates as needed for leaf growth, and falling temperatures. Small tubers are formed at the ends of the stolons and as soon as the leaf coverage exceeds 1.5 to 2 times the size of the under ground parts, the tubers starts growing. Tuber formation starts with the oldest and deepest stolons that contain the highest level of sucrose and will give rise to the largest tubers. Tuber growth varies throughout the harvest and will eventually fall into different class sizes. It is this is characteristic of the potato plant which leads to the production of tuber too small to be harvested mechanically and even by hand, staying behind on the land and giving rise to volunteer potato plants the following year. Successful tuber production is dependent on temperatures of between 15°C and 20°C and will stop when temperatures rise above 25°C (Steyn, 1999).

The tubers are the main storage organs for photosynthates and the sucrose is converted to starch stored in enlarges tuber cells. Nutrients are withdrawn from the leaves and the above ground parts start to die back. The tuber skin starts to thicken and lenticels enlarge. Variation in soil moisture content influences tuber size and extremely high temperatures can lead to drying out of the tubers and consequently a lower yield (Steyn, 1999).

Potatoes flower under long day conditions under moderate temperatures and condition of high humidity (Kumar et al., 2006). The flowers can be cross fertilised by insects, but are largely self pollinated. The fruit look like a small cherry tomato and this berry can contain 300 "true" or "botanical" seeds. This nomenclature differentiates between these seeds and seed potatoes, which are tubers. In practice the seed is seldom used in commercial plantings and mostly utilised in breeding programmes. In volunteer plants these seed are responsible for the spread of genetic material from the volunteers which can give origin to volunteers the next season (Petti *et al.*, 2007).

Where varieties are produced that are capable of producing true seed the volunteer potato plants do not only have the ability to produce large numbers of tubers, but also between 66 and 247 million seeds ha^{-1} (Steiner *et al.*, 2005). It can thus be seen that the potential for volunteer potato plants being produced from seed does exist, although the majority of volunteer potato plants originate from tubers (Bond *et al.*, 2007).

4. Management of volunteer plants

Volunteer potato plants cause numerous problems within a cropping system. They are very competitive weeds, harbour harmful insects and can be the source of disease and nematode infestations. If they are not controlled they can regenerate within the rotation crops so that they ultimately carry over to contaminate the following potato crop. It can, therefore, be seen that management of these plants is very important, but is also extremely difficult, and can only be achieved successfully using integrated management methods.

The management of volunteer potato plants should try to achieve three main goals:

a. reduce competition with the rotation crop in order to prevent yield loss;
b. prevent the production of new tubers by the volunteer potato plants within the rotation crop so that losses and control measures in the succeeding crops are reduced; and
c. restrict the numbers of surviving volunteer potato plants that can serve as hosts for pests and diseases.

There are basically five approaches that can be used to manage volunteer potato plants: preventative, cultural, mechanical, biological, and chemical. Preventative management is used to prevent the introduction of volunteer tubers to a field, so focussing on the cause of the problem. Cultural management relies on the use of cropping practices to either reduce the occurrence of the problem, or to create an environment that is less suitable for the survival of the volunteer potato plants. For example, plants that are very competitive with potatoes can be used in the rotation system, planning the rotation system in such a way that suitable herbicides can be incorporated without damage to subsequent crops, and sound agronomic management practices. Mechanical management, as the name implies, relies on the use of farming equipment to either remove or destroy the tubers or volunteer potato plants before they can create a major problem. An example of mechanical management is the incorporation of a shallow tillage operation following harvest. Biological management relies on living organisms, such as natural enemies in order to suppress volunteer potato plants. The most commonly used management method to control weeds of any type is chemical. In order to control volunteer potatoes this might include the use of suitable herbicides and soil fumigants within the rotation crops to kill the potato plants, as well as sprout inhibitors to prevent tubers sprouting.

According to Steiner *et al*. (2005) all of these methods should be combined in a collaborative approach in order to be able to successfully address the problem of managing volunteer potatoes. Each of these strategies will be discussed in more detail in the following sections of this report.

4.1 Prevention

In nature the formation of tubers is a method of survival for the potato plant. Photosynthates are stored in the tuber as a source of nutrients after the above ground parts have died back due to poor growing conditions, in order to give origin to new plants. It is also a method of reproduction, as each plant produces a multitude of tuber which each theoretically can develop in a new plant. During the growing season tuber are produced continually leading to the first tubers being the biggest, with smaller fertile tuber as small as one centimetre in diameter. During mechanical harvesting the smaller tuber stay in the soil or on the surface, medium tuber fall during the harvesting process and even large tuber can fall from the harvester and transport vehicles. Even if mechanical harvesting is followed by manual collection, many small and deeper tubers can remain behind.

Prevention of tubers which lead to volunteer plants is almost impossible and only an integrated weed control program can lead to near elimination.

Preventative management is one of the most cost effective measures for controlling any weeds, and volunteer potatoes are no exception. These strategies consist of any measure that reduces the number of tubers that remain behind in the field following harvest, and can easily be incorporated into a holistic approach to volunteer potato management. According to Steiner *et al.* (2005) the management procedures that are applicable to volunteer potato plants are harvester management, harvesting after plants are completely dead rather than still green, and the use of a sprout inhibitor. In some cases these procedures need to be coupled with agronomic management of the crop.

a. Harvest management

Proper management of the harvesting process reduces the number of tubers lost during the process, which not only results in a reduction of volunteer potatoes the following season, but also increases yields. According to Steiner *et al*. (2005) the following steps help to minimise the number of tubers that are lost during harvest:

- The blade depth should be managed in such a way as to ensure that all tubers are removed from the soil. If the blade is too shallow not all the tubers will be lifted and some will be sliced, so leaving a portion of these tubers behind in the soil. This should be coupled with the agronomic practices to ensure that the earthing up is sufficiently high so that all tubers will develop within the ridge.
- Tubers should be removed from the haulms by the harvester so that they are not carried off of the harvester.
- The trucks that receive the tubers from the harvester should be positioned in such a way as to prevent spillage.
- Harvesters should be operated in such a way as to avoid pushing tubers out around the throat of the harvester (Bullnosing).
- Soil separation and tuber transport should be maximised by using the optimal ration of forward speed to chain speed.
- The gaps between the links in the primary chain should be set in such a ways as to reduce the number of tubers that fall through the chain, but this must be compatible with the intended market.

The condition of the potato vines at harvest has been found to play an important role as both premature senescence of vines and green versus dead plants affect both the number of tubers that are left in the soil after harvest as well as the depth at which tubers are formed in the soil (Steiner *et al.*, 2005). Agronomic factors such as soil fertility and soil moisture management, as well as pest and disease control can contribute to premature vine senescence. Plants that senesce early produce a greater percentage of small tubers, and therefore more tubers will remain behind on the field at harvest, than those plants that mature later. When plants are still green at harvest, i.e. those plants that must be defoliated prior to harvest, produce more tubers that are also larger than those from plants harvested when dead. Steiner *et al*. (2005) state that in the Washington state area of the USA the numbers and sizes of tubers from green plants are double that harvested from dead plants.

In a study carried out in Washington it was found that 75% of the tubers were within 10 cm of the soil surface when the fields were harvested while the plants were still green, while only 34.2% were within this depth when plants were dead (Steiner *et al.,* 2005).

b. Use of sprout inhibitors

The use of a sprout inhibitor such as maleic hydrazide inhibits sprout development in the tubers, and so suppresses volunteer potato plant numbers in the subsequent rotation crop. This is obviously not an option when seed potatoes are being produced, but is an option for table or processing potato producers. This will be addressed in more detail under chemical control.

4.2 Cultural

Crop rotation is mainly used to reduce the pest load by planting crops not susceptible to those affecting the previous crop. During harvest and cultivation most of the plant material of the previous crop is removed or buried in the soil to decompose. Volunteer potatoes persist in the soil and are classified as weeds when they emerge in the next crop. Not only are these plants potential carriers of diseases and vectors thereof, they also compete with the succeeding crop for water, nutrients and sunlight, as well as potentially causing contamination of the suceeding crops. Some grain crops can compete with volunteer potatoes and are mostly not affected by diseases, but more sensitive crops such as onions and carrots are soon overwhelmed. Crop rotation has to be implemented together with cultivation and an integrated weed control programme (Rahman, 1980).

In the northern hemisphere mid-winter and early spring ploughing can bring buried tubers to the surface and expose them to low temperatures. This was combined by fumigation and sprout inhibiting hormone treatment. In some cases animals were chased into the fields to graze, but this has to be handled with care (Thomas & Smith, 1983). In South Africa winter temperatures seldom drop below freezing for long enough to kill exposed and shallowly buried tubers, while grazing is a costly exercise.

Proper ridging enables to blades of harvesters to cut and lift below the tubers, thus ensuring the lifting of all the tubers. This method of cultivation must be used with the correct harvesters and product transporters.

4.3 Mechanical

Repeated mechanical removal of sprouts over a period of time has a negative effect on the emergence of volunteer potatoes, but has to be continued for a long period of time as a single early season removal actually increase the production of small tubers. Again an intensive integrated weed management programme is urged (Williams & Boydston, 2002).

As sprouts from tubers buried as deeply as 20 cm below the soil surface can emerge, it is critical that the harvester be able to cut and lift this deep to catch all the tubers. This should be combined with ridge planting. This may mean redesigning of harvesters, but also careful cultivation methods. Even with enhanced harvesters the smallest tubers may still stay behind, but numbers should be seriously reduced. Together with this is the careful placing of the tubers in the transport vehicles to prevent loss during the transport of the harvest from the fields (Rahman 1980). Correct cultivation of the soil will prevent the tubers lying on the soil from being buried and thus protected. Hand collection and hoeing is ideal in cleaning the lands, but time consuming and not always economically viable in terms of time and costs (Broud *et al.,* 2007).

In Kenya a process of roughing is used to eradicate bacteria wilt carry over by volunteer plants. The sick plant is removed in its entirety; root, sprouts, tubers and soil, as well as the two plants flanking it, and all is burned. No infected potato material is therefore left in the soil. This may, however, not be feasible in very large fields (Muthoni *et al*., 2012).

The use of three to four cultivations when the potato plants are at the 9 – 11 leaf stage controlled volunteer potatoes very effectively. This mechanical control was proven to be far more effective when it followed the application of herbicides (Hughes, 1996). This contention was borne out by Boydstone & Seymore (2002), and generally the efficiency of all herbicide treatments can be improved by combining them with a tillage operation.

4.4 Chemical

Volunteer potatoes sprout and emerge unwanted in lands planted or prepared for specific crops. In this case, potatoes are seen as weeds, undesirable plants, and are treated as such. As already stated, no single method of control is be able to eradicate volunteer potatoes, and chemicals will be used as part of an integrated weed control program. Agricultural chemicals need to be chosen well, not only must they be effective agains the targets plants, they must not harm the crop or leave any undesirable residues on the harvest or plante residue left on the land (Boydston and Vaughn, 2002).

4.4.1 Sprout inhibitors

The potato plant will continue to produce tubers from the time that the first stolons thicken and the first tubers are formed until the foliage dies back totally, usually due to decreasing temperatures at the start of autumn. As soon as temperatures rise above 20°C and enough soil moisture is available, volunteer potatoes start growing and new tubers will commence forming as soon as the foliage starts photosynthesising (Steyn, 1999).

Sprout inhibitors are applied mainly to prevent tubers sprouting during storage of harvested potatoes, but can also be applied to plants at the end of the growing season. This prevents the formation of the small unuseable tubers which are often the source of volunteer potato plants. These chemicals inhibit cell division, and should therefore never be applied to seed potato fields or where spray drift can contaminate seed potato fields (Anon., 2012). According to Rahman (1980) there were three chemicals, maleic hydrazide (MH), chlorpropham (CIPC [isopropyl *N*-(3-chlorophenyl) carbamate]) and TCNB (tetrachloro-nitrobenzene), available by 1980 that would inhibit sprouting in potato tubers. Maleic hydrazide (Royal MH-30, 21.7% potassium salt of 1,3-dihydro-3.,6 pyridazindeione) has sucessfully been used in commercially produced potatoes all over the world. (PESTICIDE residues in food 1984: Evaluations 1984. WHO expert group on pesticide Residues, Rome 24 September - 3 October 1984).

Chlorpropham and TCNB are mainly used to prevent tuber sprouting after harvest and during storage, while MH has been successfully used against volunter potatoes (Rahman, 1980; Eberlen *et al.*, 1998). In South Africa chlorpropham is registered for use on potatoes in storage for the prevention of sprouting (Anon., 2007). According to Rahman (1980) this product also has herbicidal activity agains volunteer potatoes in the field.

In order to obtain maximum absorption and translocation MH is usually applied as a full cover spray to potato plants around 2 – 3 weeks after full bloom. The chemical is absorbed by the leaves and translocated to the tubers, where it usually remains and prevents sprouting from taking place (Sparks, 1978). Dow (20??) recommends the application of MH at a rate of 3 kg ha^{-1} three to seven weeks prior to defoliation. The timing of MH application is critical, as spraying too early can result in yield reduction due to a decrease in tuber size. MH prevents cell division, but does not usually limit cell expansion, unless it is applied too early during the tuber development phase (Rahman, 1980; Dow, 20??; Anon., 2012). The product is translocated to the tubers where it prevents the buds from sprouting, so that tubers left in the field do not develop the following season (Hughes, 1996; Dow, 20??).

This product has been shown to be very effective during the first year of application, visibly reducing the numbers of volunteer plants, but much less sucessful in the second year (Thomans & Smith, 1983). If MH is used properly it can result in a 70 – 80% reduction in volunteer potato plants during the next season (Eberlein et al., 1998). Newberry and Thornton (2007) showed that the suppression of volunteer potato plant emergence using MH is dependent on both cultivar treated and the size of the tubers. Even though MH treatment reduces the sprouting and emergence of shoots from tubers of all sizes, the effect is unfortunately lowest in the smaller tubers (<57 g), precisely that tuber size which causes the greatest volunteer potato problem.

4.4.2 Soil fumigation

Soil fumigation consists of the introduction of a volatile compound into the soil, primarily to suppress nematodes and other soil pathogens in crop ratotaions (Thomas & Smith, 1983; Boydston & Williams, 2003). However, fumigation with certain products has been shown to markedly reduce the number of tunbers in the soil, as well as suppressing the growth of volunteer potato plants in less competitive crops, particularly those with few registered herbicides, and may have the potential to be used as a tool in the management of volunteer potatoes (Rahman, 1980; Boydston & Williams, 2003; Steiner *et al.*, 2005). These volatile products spread through the soil atmosphere, but soil type and conditions can affect their efficiency and penetration (Rahman, 1980). It is very difficult to get uniform applications of fumigant, and together uneven distribution through the soil, or use of sublethal application rates this can lead to poor performance and variable results (Steiner *et al.*, 2005)

There are a number of products that have been used to fumigate the soil to get rid of problem organisms, such as methyl bromide, Ethyl dibromide (EDB), 1,3-dichloropropene (1,3-D) and metham sodium. Due to the high cost of fumigation it is only viable on a small area or preceeding high value crops, and only when a pest problem such as nematodes or other soil pathogens is known to exist (Rahman, 1980; Boydston & Williams, 2003; Steiner *et al*., 2005).

Early work conducted in Australia showed that ethyl dibromide (EDB) was only moderately successful in controlling volunteer potatoes, but was far more effective when applied in the cooler winter months. This was probably due to either the chemical remaining in the soil for a longer period, or the tubers being more susceptible under these conditions (Maccaulay, 1979). Injecting 1,3-D into the soil to a depth of 23 cm, 23 cm apart using chisel implement, gave excellent results in controlling volunteer potatoes during the first year, but the effect during the second year of the observations was no better than that produced by winter ploughing (Thomas & Smith, 1983).

Boydston & Williams (2003) found that applying 1,3-D by injecting through chisels in either autumn or spring, followed by a sprinkler application of metham sodium reduced the viable tubers on commercial fields by approximately 75%. The advantage of a sprinkler application of metham sodium is that it can reduce the populations of annual weeds by more than

90%, and both dormant and nondormant tubers are susceptible to this chemical. Metham sodium is registered as a herbicide in South Africa in terms of Act 36 of 1947 (van Zyl, 2012).

In the Pacific Northwest of the USA an injected application of 1,3-D was found to be more effective in managing tubers deeper in the soil than a sprinkler-application of metham sodium when winter soil temperatures were low enough to kill tubers found in the top 10 cm of soil. However, applying metham sodium via sprinklers during late summer or late spring could prove to be more efficient in suppressing shallower tubers in the years when this killing frost did not occur.

Both soil moisture and temperature during application have an effect on the dosage of fumigant required, but this is an aspect that requires further research in order to refine the application timing to obtain suppression of volunteer potato plants (Steiner *et al.,* 2005). Boydston & Williams (2003) conducted experiments in sealed glass jars and showed that tuber viability was affected by both 1,3-D and metham sodium, but that the effect was dependent on both the temperature and time that the tubers were exposed to the product. In order to obtain 90% suppression the dosage of 1,3-D varied from 41 to 151 kg ha^{-1}, and that for metham sodium from 96 to more than 480 kg ha^{-1}. Tuber mortality was affected not only by the fumigant dose, but also by temperature, time of exposure and interactions between the various factors. Effect of both products was greater as the soil temperature increased.

Factors that will determine the success of soil fumigation to suppress volunteer potato plants are a warm temperature, proper placement and dispersal of the product, as well as an adequate dose (Boydston & Williams, 2003).

4.4.3 Herbicides

Herbicides are manufactured and applied to deal with specific types of weeds in specific cropping situations. These products can be either selective, controlling certain plant species without damage to others, or non-selective, killing all plants. Products can be applied before planting (pre-plant), after planting but before the crop or weed emerges (Pre-emergence), or after the plants (crop and/or weeds) have emerged (Post emergence). Depending on the type of use they can also be classified as systemic or contact products. Systemic products are absorbed by plants and transported to the area in which they are active, and kill the plant over time, while non-systemic or contact herbicides are usually very toxic and kill the foliage on contact.

Although selective herbicides can usually be applied without causing problems to the crop, under certain conditions crop damage can occur. It is therefore, extremely important that these products are applied strictly according to the guidelines provided on the label. Care should also be taken to avoid applying these products when there is any danger of the spray drifting onto sensitive crops planted nearby. The development of glyphosate resistant plants allows the use of this usually non-selective herbicide to be applied onto these crop plants without causing damage to the crop while killing all other plants.

Ongoing research since the 1950's shows that volunteer potato plants are very difficult to eradicate using herbicides, with most products tested proving to be either ineffective or only partially effective at best (Rahman, 1980). The greatest problem is caused by the biology of the potato tuber, as large food reserves available in the parent tuber, coupled with a number of adventitious buds that can sprout after the death of the apical sprout, enables recovery from damage that would be lethal to most other weeds. The problem is further compounded by the variation in the time of emergence of volunteer potato plants. This emergence usually takes place long after many crops have been planted, which makes application timing of many post-emergence (foliage applied or contact) products very difficult to obtain good control (Lutman, 1977a). As contact herbicides will only affect the plant parts they come into contact with, the parent and/or daughter tuber is able to produce new sprouts which then emerge long after the primary plants have been killed (Rahman, 1980).

Most contact herbicides do nothing more than kill the shoots that have emerged from the soil at the time that the application takes place. Work carried out by Williams & Boydston (2002) showed that the removal of shoots resulted in a reduction in the number of tubers that are formed by the plants, with the removal of two or more shoots resulting in a reduction in tuber numbers by more than 42%. Removing shoots several weeks into the tuberisation process was more effective in reducing total tuber biomass than early shoot removal. However, this resulted in the formation of far more small (<57 g) tubers. The only way to prevent tuber production is through complete shoot removal prior to the shoots initiating tubers.

Use of single conventional herbicides has proven to be unsuccessful in the control of volunteer potatoes. Due to the devastating effect these plants have on succeeding crops such as carrots and onions as well as grains such as maize, various regimes of herbicide combinations have been researched and limited and varied success has been achieved (Koepke-Hill *et al*., 2010).

This section will firstly focus on the various herbicides that have been tested against volunteer potatoes, both soil and foliage applied, and then deal with the research that has taken place in tackling the problem in a variety of crops.

Products that have been withdrawn from use, such as DNOC, will not be dealt with even though they have been tested for use on volunteer potatoes.

4.4.3.1 Soil application

This type of herbicide treatment would expose the tubers to the herbicide for a longer period of time, and the herbicides are readily available for absorption by the roots of developing potato sprouts, so making this an attractive option for control of volunteer potatoes.

A number of herbicides that are active in the soil have been tested against volunteer potatoes over the years. The results of research that has been published in available journals are reported in this section. A great deal of the earlier work was reported on at conferences from which the proceedings are unavailable at this stage. Earlier work, reported by Rahman (1980), showed that Chloropropham, propyzamide, trifluralin, picloram, diclobenil and ethofumesate gave promising results in controlling volunteer potatoes.

Lutman (1974b) reported that acceptable levels of control could be achieved using **chloropropham**, **propyzamide** and **trifluralin** due to their levels of activity against potatoes. Subsequent field experiments, however, determined that chloropropham was not sufficiently active to control potatoes, and that the application rates at which propyzamide and trifluralin controlled potatoes would damage most subsequent crops (Lutman, 1977b). MacNaeidhe (1972) and Sijtsma et al. (1978), however, demonstrated that chloropropham gave effective control of potatoes in onions.

Chloropropham is not only a herbicide, but also a sprout inhibitor (for which use it is registered in stored potatoes in South Africa), and Sijtsma et al. (1978) showed that it was necessary to make two or three applications of chloropropham several days apart to control the growth of potatoes sufficiently to prevent interference with the onion crop. However, in field testing even an application of 12 kg ha^{-1} caused only slight inhibition of sprouting without having much effect on the yield and number of tubers produced.

Application of both **picloram** and **dichlobenil** to soils prevented potatoes from sprouting, and both of these herbicides killed the parent tubers in most instances (Lutman, 1974b). However, these herbicides both have long periods of residual activity in the soil, and Rahman (1980) felt that it was unlikely that they could be of practical use despite the excellent control of potatoes achieved.

Sijtsma et al. (1978) obtained an initial inhibition of both sprouting and shoot development of potatoes in sugar beet using **ethofumesate** at rates of 1 – 2 kg ha^{-1}, but plants recovered with time, and the treatment had very little effect on the yield and viability of tubers produced. Pre-emergence applications of ethofumesate delayed emergence of potato plants, and suppressed volunteer potatoes in a number of crops (Boydston & Seymore, 2002; Williams & Boydston, 2005). This type of application was foundto reduce tuber numbers by 28 to 45% (Williams & Boydston, 2005).

Pre-emergence application of either **atrazine** or **cyanazine** at rates of 0.6 and 1.1 kg ha^{-1} caused chlorosis and necrosis on emerging shoots of volunteer potato plants (Botdston, 2001). Applying atrazine at 1.1 kg ha^{-1} caused a reduction of new tuber formation on volunteer potato plants of approximately 90%. Atrazine, however, has the disadvantage of limiting choices of the next crop in the rotation system as it is a potent broadleaf herbicide and under certain conditions (climate and soil) can carry-over to the next season.

Applying and incorporating **Clomazone** at 0.56 kg ha^{-1} before planting gave a 100% control of volunteer potato plants 20 days after treatment, but this reduced to 78% after 34 days (Miller & Libbey, 1998).

Mesotrione, one of the triketone group of herbicides, can be applied either as a pre-emergence or post emergence treatment, although all of the literature reports on its use as a post-emergence application. According to Boydston & Williams (2005) a pre-emergence application (0.21 kg ha^{-1}) resulted in chlorotic and white shoots emerging in most cases, although occasional shoots did emerge without apparent injury. Post-emergence application on the other hand caused death of all exposed foliage.

4.4.3.2 Foliage application

One of the biggest advantages of post-emergence (POST) herbicide application is that the extent of the weed problem is already evident, and spot treatments can be used rather than applying herbicide over the entire field. Unfortunately, however, the way in which the volunteer potato sprouts, emerging over a fairly long period of time, makes a single herbicide application impossible. Generally post emergence applications should be made when the potato plants are starting to initiate tubers on the stolons.

Results from research into the effect of 27 post-emergence herbicides on potatoes conducted by Lumkes and Sijtsma (1972) proved disappointing in that potatoes were resistant to the majority of herbicides tested. Since then, however, some herbicides have been shown to have fair to good activity against potatoes and offer some hope of chemical control (Rahman, 1980).

Volunteer potato plants have proved to be fairly resistant to treatment with 2,4-D and MCPA, members of the phenoxyacetic acid group of herbicides (Aarts & Sijtsma, 1978; Lumkes & Sijtsma, 1972; Lutman & Richardson, 1978a). However, potato yield was reduced and smaller tubers were produced when plants were treated with a mixture of 2,4-D and dicamba. These effects were greater when applications took place under favourable environmental conditions. (Sijtsma et al., 1978).

Hack (1975) and Cohen et al. (1977) reported good control of potatoes in sugarbeet using **metamitron** at application rates of 8 kg ha^{-1} or higher. Research by Lutman & Richardson (1978a) with this herbicide, however, proved disappointing and control was not as good as expected. Although haulms were not damaged, or tuber production reduced, by applications of **fosamine** at rate of more than 6 kg ha^{-1}, the viability of daughter tubers was decreased. According to Rahman (1980) this non-selective product could have potential, although the lack of activity in the year of application would be a major disadvantage. The production of viable tubers was totally prevented by **triclopyr** applied at 1 kg ha^{-1} in glasshouse trials, and proved promising in the field at 0.75 kg ha^{-1} (Lutman & Richardson, 1978a). Lobb (1989) reported that **triclopyr** applied as a post emergence spray at the rate of greater than 100 g ha^{-1} injured potato plants in maize. Lutman & Richardson, 1978a concluded that these three products should be studied further as they could have the potential to control volunteer potato plants.

Contact herbicides such as **paraquat** and **diquat** kill the portion of the plant that above the soil surface either partly or completely, but plants resprout soon after treatment. Using these herbicides gives an effect similar to hoeing the land (Sijtsma et al., 1978). Although paraquat did reduce the yield of newly formed tubers, the tubers that did form were healthy and abundant (Baart & Sijtsma, 1978). Both herbicides belong to the same family, so their effect on potatoes would be expected to be similar. This would have the same effect as constant pulling of emerged sprouts.

Fernow (1959) and Lutman and Richardson (1978b) demonstrated that **amitrole** gave an acceptable level of control, but this herbicide can only be used when no crop is present or it can be applied between the crop rows as a directed application. This research showed that late spraying, even when tuber formation was in an advanced stage, was effective in controlling the plants, although spraying early proved ineffective. Experimental work has shown that this herbicide is as effective as glyphosate in controlling volunteer potatoes (Fernow, 1959; Lutman, 1978). Even though amitrole give effective control of volunteer potatoes, its use will be limited due to residual activity in the soil. This product is only registered for use in grapes in South Africa (van Zyl, 2012), so its use would be limited to non-crop situations.

Although glasshouse studies showed that ioxynil could be used for the control of volunteer it was not substantiated in field studies, where it was shown that the herbicide only temporarily defoliated young potato plants and did not provide very good control (Cox, 1974; Lutman & Richardson, 1978a). Metoxuron gave good control of potatoes in a number of trials, but the susceptibility of potato plants to treatment with metoxuron varied according to potato variety, tuber size and weather conditions (Cussans, 1978; Sajitsma et al., 1978; Lutman & Davies, 1976; Lutman, 1976, Lutman, 1977c).

Carfentrazone-ethyl is primarily a contact herbicide and requires multiple applications to manage the regrowth of new potato shoots when used alone (Steiner et al., 2005). A study conducted by Boydston (2004) demonstrated that a single post emergence application of carfentrazone-ethyl at 9 g ha^{-1} killed exposed potato shoots, but that new shoots continued to emerge. Two applications when the plants were 7 – 11 cm tall, and again 10 days later, or 3 applications at 7 – 10 day intervals commencing when the plants were 7 – 11 cm tall resulted in 77 – 87% control of volunteer potato plants and reduced the weight of tubers produced by between 76 and 96%.

Mesotrione has been shown to effectively control or suppress volunteer potatoes when applied as a post emergence spray (Steiner et al., 2005). In tests with four potato varieties it was found that a mesotrione at 0.11 kg ha^{-1} reduced new tuber production by more than 95% (Boydston & Williams, 2004). When this herbicide was applied as a single application at the time of tuber initiation at a rate of 0.07 or 0.11 kg ha^{-1} it controlled the top growth of potatoes by between 96 and 98%. Earlier applications were not as successful in controlling potato plants. This herbicide also resulted in a reduction of new tuber production and tuber weight at 6 weeks after treatment by 96 and 99% respectively in the most resistant cultivar, while no tubers were formed by the other 3 cvs. Stolon numbers at this stage, which could potentially produce additional tubers, were reduced by between 67 and 71%. According to Boydston (2006) this herbicide reduces the formation of daughter tubers in treated volunteer potato plants more than any other herbicide used for post emergence control.

Everman (2008) and Everman et al. (2010) also demonstrated good control of volunteer potato plants with a single post emergence application of mesotrione at 0.11 kg ha^{-1}, applied when the plants were between 100 and 150 mm tall. Work by Boydston et al. (2008) demonstrated similar control of volunteer potatoes using mesotrione as that obtained with fluroxypyr.

Some rotation programs can be adversely affected by the use of mesotrione as broadleaf crops such as dry beans and soya beans are very sensitive to this herbicide. Under normal conditions a 9 (SA) – 18 (USA) month waiting period between the application of this herbicide and planting a sensitive crop should be sufficient to ensure no damage, but this depends on soil and climatic conditions (Riddle et al., 2013). It would be possible to use this herbicide for spot treatment of volunteer potato plants in sensitive crops and get similar results. However, Boydston & Al-Khatib (2008) warn that mesotrione can be exuded into the soil from the treated plants and cause injury to sensitive plants up to 26 cm away from the treated plant.

Volunteer potato control of between 80 and 90% was demonstrated in research conducted at Michigan State University using 92 g ha^{-1} **tembotrione** or 5 g ha^{-1} **topramezone** (Everman et al., 2010). Tembotrione belongs to the same family as mesotrione but is not persistent in the environment except when present in loamy sands. It has a high mobility in soil and the potential to leach into ground water, but the relatively rapid rate of biodegradation may alleviate this process (EPA, 2007). Topramezone can be persistent in aerobic soils, with a half life of more than 125 days, which could cause problems for sensitive crops (EPA, 2005). A **Diflufenzopyr/Dicamba** mixture (1:2.6 mixture – STATUS®) applied at 350 g ha^{-1} (59.85 g diflefenzopyr and 154 g dicamba) gave the same levels of control (Everman et al., 2010).

Koepke-Hill et al. (2010), however, demonstrated that tembotrione (92 g ha^{-1}) and topramezone (18 g ha^{-1}) on their own were not as effective as mesotrione (105 g ha^{-1}) in controlling volunteer potatoes. At first glace it would appear that the comparison is not justified given the discrepancy in the amount of active ingredient applied. However, these are the recommended rates at which these herbicides are applied as post emergence applications for weed control in maize.

Boyston (2001) showed that an application of **fluoroxypyr** at the eight leaf stage of potato plants gave 83% control. This herbicide caused damage to the potato plant foliage and reduced the weight of tubers, but required a tillage operation 10 days after application to reduce tuber number. These results were similar to those reported by Bevis & Jewell (1996). Oglivy et al. (1989), Bond (1993) and Runham et al. (1993) also showed suppression of volunteer potato plants in a variety of crops using this herbicide. Applied to potato plants 10 – 20 cm tall at a rate of 576 g ha^{-1} this herbicide causes severe scorching and distortion of potato foliage and is translocated to the daughter tubers, so affecting the plants capacity to produce viable tubers in the year following application (Dow, 20??). Fluoroxypyr is the only herbicide that is currently registered in South Africa for the control of volunteer potatoes (van Zyl, 2012).

The sulfonylurea herbicides **nicosulfuron** and **primisulfuron** have also been shown to suppress volunteer potato plants when applied as a post emergence spray in maize (Boydston, 2001). According to Moyer (1995) and Moyer et al. (1990) this group of herbicides can persist in the soil and injure subsequent potato crops when applied to cereal crop.

Clopyralid is another post emergence herbicide that causes both distortion of stems and foliage of potato plants when applied at a rate of 200 g ae ha^{-1}. It is translocated to the daughter tubers, resulting in a reduction in their numbers, mass and viability (Dow, 20??). The effect on daughter tubers is carried into succeeding generations and reduces the threat of volunteers in the second year after treatment. However, as is the case with all of the herbicides, the extent of the control that is achieved depends on the cultivar that is being treated. Dewar et al. (2000) also showed good results using clopyralid, although the results appeared to be variable.

Although **oxyflurfen** can suppress potatoes multiple applications combined with tillage operations are required to keep volunteer potatoes under control (Steiner et al., 2005). Boydston & Seymore (2002) showed that three applications of this herbicide to onions (2, 3, and 4 – 5 leaf groth stage of the crop), each followed by a tillage operation, reduced the mass of daughter tubers by 69 – 96% and the number of tubers by 32 – 86% compared with only tillage operations.

Flumioxazin has proved to suppress volunteer potatoes and help prevent the formation of flowers and berries on potato plants applied post-emergence, at a rate of 24 – 30 g ha^{-1}. This herbicide is registered for post-emergence use in vining peas, carrots, parsnip and bulb onions. The use of this product will control volunteer potatoes with acceptable levels of crop damage (Scrimshaw, 2009). However, work conducted by Wilson et al. (2002), showed that flumioxazine was safe for use on potatoes at rates of 35 to 70 g ha^{-1} when applied as a preemergence treatment. This could possibly be ascribed to either soil or cultivar differences.

Post emergence applications of **ethofumesate** can reduce the competition effect of potatoes with the crop. This herbicide has also been shown to suppress volunteer potatoes in a number of vegetable crops (Boydston & Seymour, 2002). Williams and Boydston (2005) found that ethofumesate controlled volunteer potatoes shortly after application, but that better results were obtained with combined preemergence and postemergence applications. Generally most researchers that incorporated this herbicide in mixtures showed improved control. Unfortunately this product is not registered in South Africa.

Prometryn applied to potato plants as a post-emergence treatment initially caused chlorosis to leaf margins, within a week of application necrotic lesions and stunted growth were appartent (Williams & Boydston, 2005). The most effective treatments with prometryn were sequential sprays of 1.12 kg ha^{-1} applied at medium postemergence and late post emergence, or application at 2.23kg ha^{-1} with the addition of an adjuvant. The latter treatment could be as successful as hand weeding, depending on the conditions. Use of this herbicide reduced both the mass of tubers, as well as the number of tubers, the latter as well as the hand weeded control (Williams & Boydston, 2005).

According to Cox (1974), Sijtsma, (1977) and Lutman and Richardson (1978b) **glyphosate** was the most active of the post-emergence herbicides tested on potato. This product can also be applied prior to planting, or once the crop has been harvested (Steiner et al, 2005). The greatest advantage to this herbicide is that it not only kills the aerial parts of the plant, but is also translocated to the underground parts, including the early-formed tubers. Field trials demonstrated excellent control of potatoes with application rates in excess of 1 kg ha^{-1}, if applied sprouts had fully emerged at the time of treatment. Experimental results show that treatment with glyphosate will, unfortunately, not kill sprouts that have not emerged irrespective of how large the leaf area of other treated sprouts on the same tuber is (Cox, 1974; Sijtsma, 1977; Lutman & Richardson, 1978b). Trials conducted by Cox (1974) in New Zealand demonstrated that potatoes were effectively controlled by glyphosate applications of 0.8 kg ha^{-1}. An added advantage of glyphosate treatment was that no sprouts developed on tubers from treated plants after three months of storage.

Even though sublethal application rates of glyphosate (0.25 – 0.5 kg ha^{-1}) resulted in the production of large numbers of small tubers on treated plants, these proved to be unviable and only produced severely deformed shoots (Lutman & Richardson, 1978b). This means that very low application rates of glyphosate would not result in reliable field control during the year of treatment, but would prevent shoot emergence during the following year.

Sijtsma et al. (1978) demonstrated that adequate soil moisture is required for good results using glyphosate and at temperatures that result in optimal growth of the potato plants. Today we know that glyphosate gives the best control when it is applied under conditions that result in actively growing weeds as this results in the best translocation of the herbicide throughout the plant. If applied during hot and dry conditions plants die too quickly for effective translocation to the tubers to take place.

Glyphosate can only be used selectively in crops that are genetically modified to be resistant to the herbicide, the so-called Roundup-Ready® crops. This means that this particular herbicide can only be used as directed sprays between the rows of sensitive crops, or using spot treatments on heavily infested areas. However, glyphosate will result in excellent control of volunteer potato plants where there is sufficient time between soil preparation and planting the new crop for the volunteer potato plants to sprout fully before the herbicide is applied. Unfortunately this is not an option in very intensive production.

This product can also be used as a pre-plant application in crops that are planted late, or under no-till conditions in order to kill volunteer potatoes that emerge early. Unfortunately new shoots tend to emerge after two or three weeks, meaning that other methods then need to be applied to adequately manage the problem of daughter tuber production. Far less regrowth occurs after herbicide application, however, if glyphosate application is carried out once the maximum number of shoots has emerged (Steiner et al, 2005). Studes conducted in the USA have also shown that glyphosate can be applied before harvesting wheat when the grain is in the hard dough stage (≤ 30% moisture content in the grain) to control volunteer potatoes, with the exception of a seed crop. This option is not very effective, however, as the potato plants are usually drought stressed at this stage, below the canopy, and have already formed tubers.

Studies have shown that if glyphosate is applied to potato plants when the tubers have attained a weight of approximately 60 g can reduce the tuber viability, but these results have been variable. The results obtained from this application depend very much on the size of the potato plants and the tubers, the condition of the plants, as well as the availability of moisture. Multiple applications may be required in order to obtain adequate suppression (Steiner et al., 2005).

Lutman and Richardson (1978) and Oglivy et al. (1989) demonstrated low levels of volunteer potato control by glyphosate when applied at an early stage. Boydston (2001) found similar levels of control of potato plants when glyphostae was applied at either the six or eight leaf stage, but that tuber mass was reduced more by applications at the later stage when tubers had already begun to form. This is a logical observation as translocation of the herbicide into the developing tubers would be far better once tubers start forming on the plant.

Smid and Hiller (1981) reported that abnormal sprouts emerged from tubers that originated from plants where glyphosate had been applied prior to tuber initiation. They found that potato control was adequate at applications of 0.28 to 0.56 hg ha^{-1}, and that increasing the application rate beyond this did not significantly improve control. This differs appreciably from the finding of Lumkes (1974) who stated that complete control of volunteer potato plants was obtained by applying 4 – 5.5 kg ha^{-1} of glyphosate after the plants had initiated tubers.

Generally the addition of ammonium sulphate is recommended to improve the absorption, so improving the activity of glyphosate. Lutman and Richardson (1978) reported increased activity of glyphosate on potato plants with the addition of ammonium sulphate in glasshouse trials, but Boydstone (2001) found that ammonium sulphate produced no increase in activity when glyphosate was applied to volunteer potato plants in the field.

Boydston (2006) states that applications of **imazamox** are also effective in killing potato plants and reducing the daughter tuber mass, and that repeated application of contact (post-emergence) herbicides such as fomesafen and glufosinate can also be effective in controlling potato plants. Steiner et al. (2005) rated the control given by herbicides registered in the Pacific North West for the control of volunteer potato plants (Table 1). From this table it can be seen that there are a number of herbicides registered for use against volunteer potatoes in these states about which no verifiable data could be obtained in the scientific journals which are easily obtainable.

A list of herbicides that have been tested successfully against volunteer potatoes is given in Addendum 1.

TABLE 1 Level of control of a number of herbicides used for volunteer potato management in the Pacific North West states of the USA

Level of control	Herbicides
Fair	2,4-D; Bromoxynil; Carfentrazone-ethyl; Clomazone; Clopyralid; Ethofumesate; MCPA; MCPB; Paraquat; Pyridate
Fair – Good	1,3-D*; Dicamba; Fluroxypyr; Fomesafen; Glyphosate; Imazamox; Imazethapyr; Maleic hydrazide (MH)[a]; Metham sodium*; Metsulfuron-methyl; Oxyfluorfen; Thifensulfuron-methyl
Good	Atrazine; Mesotrione; Picloram

* - Soil fumigant
a – Sprout inhibitor

4.4.3.3 Mixed application

Considering the information provided on single herbicide applications in conjunction with the biology of volunteer potato plants it is not surprising that a great deal of research has been conducted on the use of more than one herbicide to control these plants. This can comprise of the use of a pre-emergence herbicide application, followed up by the use of a post-emergence application to control later emerging sprouts. The other option that many have studied is the use of more than one post-emergence application, or applying a mixture of herbicides with different modes of action.

Volunteer potatoes have been controlled effectively, and tuber weight reduced by more than 95%, through a pre-emergence application of atrazine at 1.1 kg ha^{-1} followed by a post emergence application of a mixture of dicamba (0.28 kg ae ha^{-1}) and 2,4-D (1.1 kg ae ha^{-1}). The use of fluroxypyr (0.22 kg ae ha^{-1}) as a post emergence application following a pre-emergence application of atrazine has also proved very effective in controlling volunteer potato plants. The incorporation of atrazine, however, can limit the choices of follow up crop in the rotation system as it can carry-over to the next season under certain climate and soil conditions (Boydston, 2001; Steiner et al., 2005).

In onions it was shown that the use of a bromoxynil (0.2 kg ha^{-1}) and oxyfluorfen (0.17 kg ha^{-1}) mixture at the 2, 3, and 4 – 5 leaf stage of onions reduced tuber mass by 69 – 96% and tuber number by 32 – 86% when combined with a cultivation after each herbicide application. The use of two applications of fluroxypyr at 0.3 kg ha^{-1} together with bormoxynil at 0.2 kg ha^{-1} follwed by a tillage operation resulted in the reduction of tuber mass by more than 90%, but this practice resulted in damage to the onion crop. A pre-emergence application of ethofumesate (0.6 kg ha^{-1}) followed by two post emergence applications of a mixture of ethofumesate (0.3 kg ha^{-1}) and bromoxynil (0.2 kg ha^{-1}) was also successful in reducing both mass and number of tubers on volunteer plants, but was far more successful when a tillage operation followed the post emergence herbicide application (Boydston & Seymour, 2002).

Williams & Boydston (2005) found excellent control (similar to a hand weeded treatment) of volunteer potatoes when ehtofumesate wat applied as a preemergence treatment (3.4 kg ha^{-1}), followed by an application of 2.2 kg ha^{-1} early post emergence (plants approximately 7 – 11 cm tall). This treatment also reduced tuber mass. According to Dow (20??) a tank mix of clopyralid with ethofumesate is one of the best treatments against volunteer potatoes.

Boydston (2004) stated that one of the most effective treatments tested against volunteer potato plants using carfentrazone-ethyl and dicamba were a single application of a combination of the two herbicides at 9 and 280 g ha^{-1} respectively when the potato plants were 15 – 18 cm tall.

A study conducted at Washington State University by Millar & Libbey (1998) showed that only two herbicide mixtures achieved a control of greater than 90%. A mixture of primusulfuron (0.03 kg ha^{-1}) and dicamba (0.07 kg ha^{-1}) gave 94% control of volunteer potatoes, while a 91% control rate was achieved using a mixture of fluroxypyr (0.28 kg ha^{-1}) and MCPA (0.56 kg ha^{-1}).

A mixture of fluroxypyr (0.78 L ha^{-1}) and atrazine (1.12 kg ha^{-1}) gave good suppression of volunteer potatoes, while the addition of atrazine at rates of 0.56 or 1.12 kg ha^{-1} to mesotrione, tembotrione, topramezone and a diflufenzopyr/dicamba mixture improved control to 96% (Everman et al., 2010). The addition of tribenuron-methyl at 18 g ha^{-1} in a tank mix with fluoroxypyr (576 g ha^{-1}) provided superior levels of potato control in cereals (Dow, 20??).

Work in sweet corn demonstrated that the application of mesotrione at rates of 0.035, 0.07 and 0.1 kg ha^{-1}, atrazine at 1.1 kg ha^{-1} or a combination of mesotrione and atrazine reduced the number of new tubers produced to <1.1 per plant (Boydston et al., 2008). This showed that the addition of atrazine to the mesotrione treatment was not required to improve potato control.

Research conducted by Koepke-Hill et al. (2010) showed that the addition of atrazine at a rate of 0.56 kg ha^{-1} to mesotrione at a rate of 105 g ha^{-1} in post emergence applications did not improve control of potatoes, a finding that concurs with that of Boydston et al. (2008) working with sweet corn. The next best treatments (providing approximately 14 – 17% poorer control) was provided by the addition of bromoxynil (280 g ha^{-1}) or bentazon (0.56 kg ha^{-1}). In this case control was monitored six weeks after treatment with the herbicide. Over the two seasons that this trial was conducted the results provided by the treatments varied, although the control provided by the mesotrione application was constant. Boydston et al. (2008) also encountered this variation in results between the seasons in their trial. These results show the importance of environmental conditions in determining the efficacy of herbicide applications.

The efficiency of all herbicide treatments can be improved by combining them with a tillage operation or late season defoliation by phytophageous insects.

5. Possibilities for chemical control of volunteer potato plants in South Africa

Although there are herbicides available today that can successfully deal with almost any weed problem, the use of some herbicides may restrict the options for future crops on the land. Herbicides should be managed properly and strictly according to the label guidelines, as this determines the way in which the product may legally be used and the application rates to be used. If this is not done there is no legal recourse in the case of problems with the product. Some weeds, such as volunteer potato, are extremely difficult to kill using herbicides, and most products are only partially effective at best, or entirely ineffective (Lumkes & Sijma, 1972; Lumkes, 1974; Lutman, 1974; Garnier et al., 1977; Sijtsma, 1977) (as cited by Rahman, 190).

5.1 Current situation

Presently in South Africa there is only a single herbicide that is registered for the control of volunteer potatoes in terms of Act 36 of 1947, and this is fluoroxypyr. This product is known under the trade names Starane 200 EC, Tomahawk 200 EC and Veloxypyr 200 EC. In order to control potatoes the product needs to be applied when most of the potatoes have emerged and are in the six leaf stage (van Zyl, 2012).

Although this is the only registered product, many farmers make use of picloram (Access or Browser) to deal with volunteer potatoes. This herbicide is very effective in killing potato plants and also prevents potatoes sprouting. However, the long period of residual activity found with this herbicide can result in later problems.

A study of the South African scientific literature from the early 1970's until the present showed that there has been no published research into the problem of controlling volunteer potato plants. This is extremely interesting given the potential impact of volunteer potato plants for potato producers.

5.2 Important points with chemical control

The important thing to remember is that volunteer potatoes are very difficult to kill due to the reasons that have been laid out above in the biology of the potato. There are certain characteristics that a herbicide would need to meet that would make it suitable to control volunteer potato plants. These characteristics are as follows:

a. It should be systemic
b. It must kill potato plants
c. It can be applied either pre- or post-emergence, although a pre-emergence application would be preferable to kill the plants as they emerge from the soil.
d. It needs to have a relatively short period of residual activity, certainly no longer than 6 months, in order to fit in with the crop rotation system.
e. It should be relatively cheap

f. It need to either kill all potential sprouts on the tuber, or inhibit further sprouting from the tuber
g. It must be selective, i.e. not damage the crop in which it is being applied
h. It needs to give consistent control
i. It must be equally effective on all cultivars

5.3 Herbicides

A number of products have been tested in potato producing countries for their efficacy against volunteer potatoes, with varying degrees of success. One of the biggest problems is finding a suitable product that fits into the rotation program used by producers, as many products are capable of controlling volunteer potato plants, but can be phytotoxic to other plants in the rotation system. Fortunately most producers in South Africa follow potatoes with maize, making the choice far easier.

This section of the literature study will take the herbicides that have been identified as controlling volunteer potato plants overseas and look at the registrations in South Africa in terms of Act 36 of 1947. Those products that are registered in South Africa will be addressed in section 5.3.1. The products that are not registered in South Africa at this stime will be sub-divided into two groups. The first group of products, addressed in section 5.3.2, are those products whose manufacturers are represented in South Africa. If, however, the manufacturer is not represented in South Africa, the product will not be included in this review, no matter how effective the product is against volunteer potatoes, as it cannot be tested under South African conditions.

The only products that may be used in South Africa are those that are registered for use against volunteer potatoes in terms of Act 36 of 1947. The use of any other product for this purpose, even if registered for use on crops in South Africa, cannot be guaranteed, and usage outside of label recommendations will invalidate any claim for damages against the company concerned.

5.3.1 Available in South Africa

The only product available in South Africa that is registered for the control of volunteer patato plants is fluroxypyr. This is available as Tomahawk 200 EC from Makhteshim-Agan, Starane 200 EC from Dow AgroSciences, and Veloxypyr 200 EC (only for use in the Delmas area of Mpumalanga) from Arysta Lifesciences. All products are registered to control volunteer potatoes in maize and wheat, at rates of between 0.75 and 1.25 L ha^{-1}, although Starane 200 EC is also registered for use in Eragrostis. The product should be applied as soon as most potato plants have emerged and are in at least the 6 leaf stage. Only potatoes that have emerged will be controlled (Arysta Lifescience, 20xx; Dow AgroSciences, 20xx; Makhteshim-Agan, 2011).

There are a number of products that have been tested overseas within the last 10 years that have shown promising results in controlling volunteer potatoes (Table 2).

TABLE 2 South African registered herbicides with registration in the US for volunteer potato control (Steiner et al., 2005, van Zyl, 2012)

Active ingredient (Chemical name)	Trade name	Concen-tration	Company	Crop/s	Application Type	Contact / Systemic	Level of control
Atrazine	Agrazine SC Atraflo 500 SC Atranex 500 SC Atrazine 500 SC Atrazine SC Ciplazine 500 Atranex 90 WG Atrazol Gesaprim 90 WG	500 g L^{-1} 900 g L^{-1}	Universal Villa Plaaskem Makhteshim-Agan DOW Tsunami (Arysta) GAP Chemicals CIPLA Agricare Sipcam Syngenta	Canola Grain Sorghum Maize Pineapples Sugarcane	Soil Foliar	Contact	Good
Bromoxynil	Brominex EC Bromotril Bromoxynil EC Bromoxynil 225 EC Bromoxynil 225 Camatop 225 Voloxynil B225 EC Bromotril 400 EC Bentrol Super Brominal Super Buctril-DS Pardner Super Bromotril P 500 SC	225 g L^{-1} 225 g L^{-1} 225 g L^{-1} 225 g L^{-1} 225 g L^{-1} 225 g L^{-1} 225 g L^{-1} 400 g L^{-1} 450 g L^{-1} 450 g L^{-1} 450 g L^{-1} 450 g L^{-1} 500 g L^{-1}	Plaaskem Makhteshim-Agan Universal RT Chemicals Tsunami (Arysta) Villa Volcano (Arysta) Bayer	Barley Grain Sorghum Lucerne Leguminous pasture Maize Oats Wheat	Foliar	Contact	Fair
Carfentrazone-ethyl	Aurora 40 WG	400 g kg^{-1}	FMC Chemicals	Barley Wheat	Foliar	Contact	Fair
Clomazone	Command 4 EC Kalif 480 EC	480 g kg^{-1}	FMC Chemicals Makhteshim-Agan	Soya Beans Tobacco	Soil	Systemic	Fair
2,4-D	2,4-D Dimetylamine 2,4-D Amine 480 SL 2,4-D Amine SL	480 g L^{-1}	Sipcam Dow Universal	Barley Grain Sorghum Grass pastures	Foliar	Systemic	Fair

	2,4-D Amine 2,4-D Amine 480 2,4-D Amino SL Avi-Amine 7,2 SL 2,4-D Ester 500 EC 2,4-D Ester EC 2,4-D Ester 2,4-D Iso-octyl Ester Wildebees Ester	 720 g L^{-1} 500 g L^{-1}	Tsunami (Arysta) Plaaskem GAP CIPLA Villa Avima Volcano (Arysta)	Maize Potatoes Rye Sugarcane Wheat			
Dicamba	Banvel 480 SL Dominator	480 g L^{-1} 700 g L^{-1}	Syngenta Klub M5	Grain Sorghum Maize Wheat	Foliar	Systemic	Fair - Good
Fluroxypyr	Starane 200 EC Tomahawk 200 EC Voloxypyr 200 EC	200 g L^{-1}	Dow Makhteshim-Agan Volcano (Arysta)	Grass pastures Maize Wheat	Foliar	Systemic	Fair - Good
Fomesafen	Flex	250 g L^{-1}	Syngenta	Dry Beans Green Beans Groundnuts Soya Beans	Foliar	Contact	Fair - Good
Glyphosate (Only on RR crops)	Mamba Max 480 SL Touchdown Forte HiTech Panga Plus 540 SL Roundup Power Max Slash Plus 540 SL	480 g ae L^{-1} 500 g ae L^{-1} 540 g ae L^{-1}	Dow Syngenta Villa Monsanto Universal	Cotton Maize Soya Beans	Foliar	Systemic	Fair - Good
Imazamox	Cysure Imazamaxx	40 g L^{-1}	BASF Meridian Agritech	Canola Clovers Lucerne Leguminous pasture Medics	Foliar	Systemic	Fair – Good
Imazethapyr	Equate SL Hammer Imazethapyr 100 SL	100 g L^{-1}	Meridian Agritech BASF Universal	Dry Beans Groundnuts Soya Beans	Foliar	Systemic	Fair - Good

	Mallet SL Vezir 240 SL	 240 g L^{-1}	Villa Makhteshim-Agan				
MCPA	Avi-D-Weed Makhro MCPA MCPA 400 SL MCPA MCPA 700 WSG Missile	400 g L^{-1} 700 g L^{-1}	Avima Makhro-Agro Dow Villa Universal GAP Chemicals Volcano (Arysta) Tsunami (Arysta) Klub M5	Barley Grass Pastures Grain Sorghum Maize Oats Potatoes Rye Sugarcane Wheat	Foliar	Systemic	Fair
Mesotrione	Astran 480 SC Callisto Cantron SC	480 g L^{-1}	Universal Syngenta Villa	Maize	Soil Foliar	Systemic	Good
Metham sodium	Ag-fume Herbifume Nemasol Vapam	510 g L^{-1}	Ag-Chem Plaaskem D&J Agro Pesticides Universal	Seedbeds	Soil	Fumigant	Fair - Good
Metsulfuron-methyl	Prism 20 WG Brush-off Enhancer Metsulfuron-methyl 600 Romex Makhro Nicanor Naconor 50 WP Climax	200 g kg^{-1} 600 g kg^{-1} 200 g kg^{-1} 500 g kg^{-1} 600 g kg^{-1}	Meridian Agritech Du Pont Klub M5 RT Chemicals Bitrade Consulting Makhro-Agro Makhteshim-Agan Volcano (Arysta)	Barley Oats Wheat	Foliar	Systemic	Fair - Good
Oxyfluorfen	Fenox Galigan 240 EC Goal 2XL 240 EC Orion 240 EC Oxyfluorfen 240 Victory 240 EC Goal 480 EC	240 g L^{-1} 480 g L^{-1}	Meridia Agritech Makhteshim-Agan Dow Universal RT Chemicals Villa	Broccoli Brussels Sprouts Cabbage Cauliflower Garlic Onions Sugarcane	Foliar	Contact	Fair – Good

Paraquat	Skoffel SL Agroquat Avi Parakwat Ciplaquat 200 Gramoxone Nexus Araquat SL Paragone SL Paraquat Paraquat 200 Shinquat 200 SL Skoffel Super	145 g L^{-1} 200 g L^{-1}	Universal Plaaskem Tsunami (Arysta) Avima CIPLA Agricare Syngenta Volcano (Arysta) Makhro-Agro RT Chemicals AG-Chem	Any (Directed sprays)	Foliar	Contact	Fair
Picloram	Access 240 SL Browser Picloram 240 SL	240 g L^{-1}	Dow Volcano (Arysta) RT Chemicals	Bush encroachment	Foliar	Syatemic	Good
Pyridate	Lentagran EC Lentagran WP	640 g L^{-1} 450 g kg^{-1}	Volcano (Arysta)	Maize	Foliar	Contact	Fair
Thifensulfuron-methyl	Twister	750 g kg^{-1}	Klub M5	Barley Oats Wheat	Foliar	Systemic	Fair - Good
Maleic hydrazide (sprout inhibitor)	Royal MH-30	250 g L^{-1}	Chemtura	Onions	Foliar	Systemic	Fair - Good

5.3.2 Available overseas (South African companies)

These are products that are manufactured by companies with offices in South Africa, and although the products are not available on the South African market it might be possible to obtain some of the products for testing purposes. These products are shown in Table 3.

TABLE 3 Herbicides from SA companies that show promise for volunteer potato control, but are registered overseas

Active ingredient	Product	Company
Dichlobenil	Prefix D Casoron	Syngenta Chemtura
Ethofumesate	Tramat 500 SC	Bayer Crop Science
1,3-D	Telone II	Dow Agrosciences
MCPB	Can-Trol	Bayer Cropscience
Fosamine	Krenite S	Du Pont Agrosciences
Ioxynil*	Actril DS Foxpro DT Foxtril Super Oxytril Oxytril M Totril TwinTak	Bayer Crop Science Makhteshim-Agan Makhteshim-Agan Bayer Crop Science Bayer Crop Science Bayer Crop Science Bayer Crop Science
Primisulfuron	Beaon Exceed Northstar Spirit	Syngenta Du Pont Agrosciences Syngenta Syngenta

* - Available in a mixture with bromoxynil (Voloxytril 400 EC – Arysta Lifesciences)

5.4 Problems

Many problems with the use of herbicides are caused by off-label use of the product. The recommendation on the label should be followed religiously or crop damage can result with high application rates, or poor weed control at low application rates. Unfortunately at this stage only Fluoroxypyr is registered for use to control volunteer potato plants. As a result many farmers are using products that are not registered for this purpose.

The environmental conditions during application of the products can play an important role in the success or failure of any given product, but this is particularly important when using post emergence applications. For successful control with these products they should be applied when the weed is actively growing and not suffering from any for of stress, as this will reduce the efficacy of the product. Soil conditions play an important role in the use of all herbicides. The clay and organic matter content of the soil affects the rate of application and residual effects of pre-plant or pre-emergence herbicides, while the soil moisture content plans an important role in the uptake of soil applied herbicides and also determines the success of post emergence herbicide applications. Again, following the instructions given on the herbicide label, and knowing exactly when conditions are suitable to apply the particular product can reduce problems.

It is very important to bear the next crop in the rotation system in mind when choosing a chemical for the control of volunteer potatoes. The reason for this is that certain of the products that control volunteer potatoes can have fairly long periods of residual activity in the soil, and have a negative impact on sensitive crops if these are planted while the residual activity of the herbicide is still sufficiently high to cause damage. Once again let the herbicide label be your guide, as this will give information on the waiting periods prior to planting sensitive crops after treatment with the herbicide.

Another thing that must be borne in mind, and one in which the herbicide label will not be of any assistance, is that of the cultivar being used. Not only is the crop cultivar important, but also the cultivar of the volunteer potatoes that need to be controlled. The reason for this being that cultivars differ in their sensitivity to any given herbicide, which can mean that the crop can shown signs of damage, or that the potato plants are not well controlled by the specific herbicide. The only way to overcome this problem is to spray a small portion of the land initially and observe the results on both crop and weed. Only if no damage resuts should the go-ahead be given to spray the entire planting.

The last problem that has to be taken into account is the purpose of the potato planting. If plantings are only for table or processing potatoes for example, it is possible to apply sprout inhibitors to the crop in order to reduce the problems caused by volunteer potatoes the following season. If, however, the crop is to be used to produce seed potatoes, this is no longer an option and other methods need to be applied.

5.5 Adaptability within the rotation system

At this stage a list of all of the crops that are used to follow potatoes within the rotation system is not available, so the selection of herbicides within the common rotation steams cannot be compiled. The most important crop would, however, appear to be maize. This is a great advantage as most of the herbicides that have been successfully used to control volunteer potatoes are registered for use in this crop in South Africa.

This section will be completed at a later stage.

6. Conclusion

Controlling volunteer potatoes is a great deal more difficult than the control of most other weeds. The plant is hardy, a vigorous grower, and the biology and physiology of germination make it difficult to achieve control. The absence of cold winter temperatures makes the control of volunteer potato populations in South Africa very difficult. The population of tubers that are either exposed on the soil surface, or very close to the soil surface will be reduced by bird and rodent damage, grazing animals, and exposure to fungi and bacteria. It can thus be seen that the management of tuber depth is crucial.

The problem of volunteer plants can reduce the positive effects of crop rotation in reducing soil-borne, and other diseases, insect pests and nematode populations. These plants make very competitive weeds and can result in large yield reductions, particularly in sensitive crops, and can create large problems for the producers of seed potatoes. Some varieties of potato are capable of producing large numbers of true seed as well as tubers if not controlled, and although the main volunteer problems are caused by the tubers, germinating seeds can also cause problems if plants are allowed to form seed.

Many methods of control are available to the producer, including cultivation, crop competition and the use of herbicides. Unfortunately not one of these methods is the silver bullet, and combining these methods in an integrated plan would appear to be the best management option.

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ADDENDUM 1

SUMMARY TABLE OF HERICIDES TESTED AGAINST VOLUNTEER POTATO GIVING THEIR AVAILABILITY AND REGISTRATIONS IN SOUTH AFRICA

Chemical (Active ingredient)	**Application type (PRE / POST)**	**Level of control (if rated)**	**SA Availability**	**Crops**
Cloropropham	PRE	Poor	Sprout inhibitor	Potatoes
Propyzamide	PRE	Poor	Yes	Orchard crops, lettuce, Lucerne & Leguminous pastures
Trifluralin	PRE	Poor	Yes	Orchard crops, Barley, Canola, Wheat, Cabbage, Carrots, Cotton, Cow peas, Dry beans, Kidney beans, Groundnuts, Sunflowers, Tomatoes, Soya beans
Picloram	PRE (?)	Excellent	Yes	Bush encroachment
Dichlobenil	**PRE**	**Excellent**	**No**	
Ethofumesate	**PRE / POST**	**Poor - Fair**	**No**	
Atrazine	PRE	Good	Yes	Canola, Grain sorghum, Maize, Pneapples, Sugarcane
Mesotrione	PRE / POST	Good	Yes	Maize
Cyanazine	PRE		Yes	Maize, Sugarcane, Sweetcorn, Cotton, Peas, Hops, Rooibos tea
Clomezone	PRE	Fair		Tobacco, Soya beans
1,3-D	**PRE**	**Fair - Good**	**No**	
2,4-D	POST	Poor - Fair	Yes	Barley, Grain sorghum, Grass pastures, Maize, Potatoes, Rye, Sugarcane, Wheat
MCPA	POST	Poor - Fair	Yes	Barley, Grass pastures, Grain sorghum, Maize, Oats, Potatoes, Rye, Sugarcane, Wheat
MCPB		**Fair**		
Metamitron	POST		Yes	Beetroot, Sugar beet
Fosamine	**POST**		**No**	
Triclopyr	POST		Yes	Sugarcane
Diquat	POST		Yes	Orchard crops, Directed application
Paraquat	POST	Fair	Yes	Orchard crops, Directed application
Amitrole	POST		Yes	Grapes
Ioxynil	**POST**		**No**	**Only in a mixture with bromoxynil**
Metoxuron	**POST**		**No**	
Glyphosate	POST	Fair - Good	Yes	Roundup Ready® Crops, Directed application
Dicamba	POST	Fair - Good	Yes	Grain sorghum, Maize, Wheat
Carfentrazolne-ethyl	POST		Yes	Orchard crops, Grapes, Hops, Tea, Wheat
Fluroxypyr	POST	Fair - Good	Yes	Grass pastures, Maize, Wheat

Oxyfluorfen	POST	Fair - Good	Yes	Broccoli, Brussels sprouts, Cabbage, Cauliflower, Garlic, Onions, Sugarcane, Grapes, Orchard crops
Tembotrione	POST		Yes	Maize
Topramezone	POST		Yes	Maize
Nicosulfuron	POST		Yes	Maize
Primisulfuron	**POST**		**No**	
Clopyralid	POST	Fair	Yes	Canola
Flumioxazin	POST		Yes	Orchards crops, Soya Beans
Prometryn	POST		Yes	Peas, Carrots, Cotton
Imazamox	POST	Fair - Good	Yes	Canola, Clovers, Lucerne & Leguminous pastures, Medics
Metoxuron	**POST**		**No**	
Bromoxynil	POST		Yes	Barley, Grain sorghum, Lucerne & Leguminous pastures, Maize, Oats, Wheat
Pyridate	POST	Fair	Yes	Maize
Fomesafen	POST	Fair - Good	Yes	Dry beans, Green beans, Groundnuts, Soya beans
Imazethapyr	POST	Fair - Good	Yes	Dry beans, Groundnuts, Soya beans
Metham Sodium	POST	Fair - Good	Yes – soil fumigant	Seedbeds
Metsulfuron-methyl	POST	Fair - Good	Yes	Barley, Oats, Wheat
Thifensulfuron-methyl	POST	Fair - Good	Yes	Barley, Oats, Wheat
Maleic hydrazide		Fair - Good	Sprout inhibitor	Onions

Products printed in bold are not available in South Africa