Mini-ridgers: Lethal burial depth for controlling intrarow weeds

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Permanent Agriculture and Horticulture Science and Extension

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1. Summary

- Mini-ridgers are a highly effective weeding tool for controlling intrarow weeds through burial.
- As they kill weeds entirely by burial, they don't require the hot dry weather most other weeders need for maximum weed kill.
- They also work across the full range of soil types and conditions including stony and rough tilths.
- They are exceptionally mechanically simple, and therefore inexpensive.
- They can consistently achieve close to 100% weed control, including the most critical close-to-crop plant weeds.
- Despite these favourable attributes, to date very little research has been undertaken to determine minimum lethal burial depths and none has determined maximum safe burial depths. This report details the research undertake by the Future Farming Centre to address this gap.
- Three successive years of trials were undertaken to achieve the correct methodology. The final result, however, was very clear.
    - Where weeds / crop are two or more centimetres higher / clear of the top of the ridge survival is close to 100%;
    - Where weeds / crop have only one centimetre clear of the ridge, or the ridge is level with their top most part, mortality increases very rapidly;
    - Where weeds / crop are covered with just one centimetre or more of soil, mortality is 95% or greater;
    - Plant species had no effect on survival - i.e., the results were the same for all species.
    - Plant size (range of 10 mm to 133 mm) had no effect on survival, i.e., the results were the same regardless of plant size.
- Based on these experiments, a very simple rule of thumb is possible for successful implementation of mini-ridging in the field.
    - The weeds must be covered by 1 cm or more of soil to ensure a high mortality rate;
    - The crop must extend 2 cm or higher than the top of the ridge to ensure high survival rate.
    - There must therefore be at 3 cm height difference between weeds and crop.
    - Where lower mortality rates are acceptable burial at 0 cm and -1 cm will achieve some weed mortality.
- It would be valuable to confirm these results and the rule of thumb with field experiments across a range of crops and weeds.

2. Introduction

In Merfield (2014) the use of 'mini-ridgers' for control of intrarow weeds was discussed along with preliminary research results on the depth of burial required to kill weeds / plants. This report supersede the research results on lethal burial depth of the previous report and is a stand alone mini-ridgers information source.

3. Mini-ridgers

Modern interrow hoes, particularly when combined with computer guidance systems, e.g., computer vision systems or RTK GPS tractor and implement autosteer, mean that non-chemical control of interrow weeds is now a straightforward and highly effective farming operation. It is the intrarow (within the crop row) weeds that are the final frontier of non-chemical weed control. Merfield (2014) detailed a number of intrarow weeders including finger, torsion, vertical spring tine, and thermal weeders and mini-ridgers. Particular focus was given to mini ridgers due to a number of benefits.

- Their engineering is exceptionally simple being made only of flat steel bar;
- They work in a wide range of crops and crop growth stages;
- They work in all soil textures, structures and a range of stoniness;
- Their efficacy is mostly independent of weather conditions and soil moisture;
- They can achieve a very high weed kill, e.g., > 95%.

The technique works by creating a small, e.g. two to six centimetre high, ridge of soil within the intrarow, thus burying small weedlings but leaving the larger crop plants above the soil mound (Figure 1).

Figure 1. Mini-ridger in transplanted cabbages.

Mini-ridging is somewhat akin to potato ridging, but on a much smaller scale. The key to the system is the correct design of the ridgers, which counterintuitively, the simplest design works best: being just a flat metal bar with the long edge horizontal to the ground, angled at about 45° to the direction of travel / crop row, with the short edge set vertically (not tilted) and placed in the interrow (Figure 2), such that it funnels a small wave of soil into the intrarow. This design means the ridge is created from the bottom upwards, so soil is not falling onto the top of the crop with the potential to damage it, nor contaminating the crop with soil, e.g., soil getting into the heart of lettuces.

The standard design has a pair of flat bars in a V shape with a leg attached at the centre of the V with the ridger / leg placed in the center of the interrow. There are also single blade designs (Figure 2, top right) which are used where there are very wide interrows, e.g. field tomatoes, squash, maize/sweetcorn, and on outside rows of a bout.

Figure 2. Various mini-ridger designs: Basic, vertical leg, V design, with two different ridger heights (top left), single blade, rotatable design on a rotary hoe / rotovator with wide crop gaps for weeding field tomatoes (top right), V design on a sloping sprung loaded leg (bottom left) and vertical leg V design with adjustable wings mounted behind an A blade hoe (bottom right).

The critical design criteria is the height of the flat bar, as this determines how much soil is moved laterally, which in turn determines the size of the ridge. Very simply, a small bar height creates a small ridge as the bar can only push a wave of soil sideways the same height as the bar, as any excess soil simply flows over the top. This means that the ridge height can be precisely controlled by using blades of different heights (Figure 3).

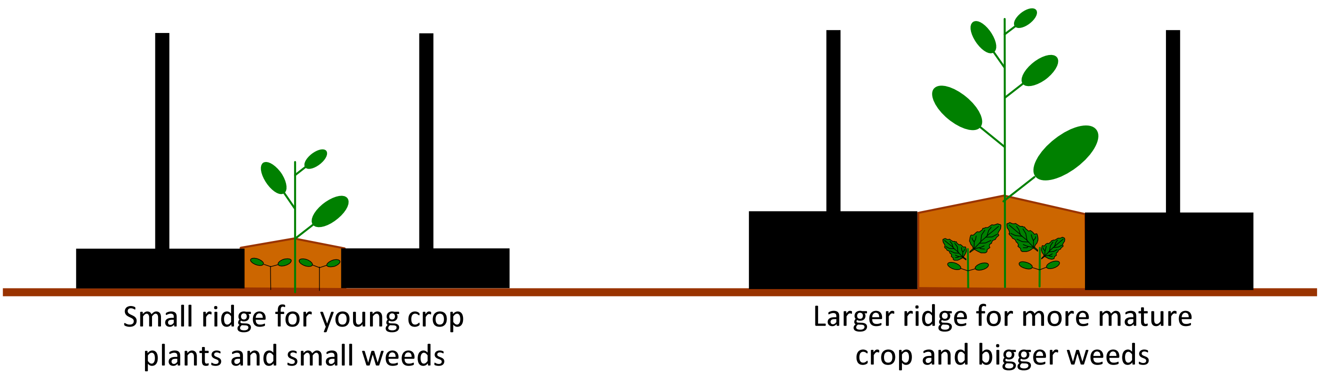

Figure 3. Diagram of how the mini-ridger blade height affects ridge height.

The other main design criteria, are:

- The angle of the ridging bar to the crop row / direction of travel. 45° (a 90° V shape) is about as wide as angle as practical otherwise soil will not flow along the front of the blade, while narrower angles e.g. up to 30° (a 60° V) are better suited to higher speeds as they don't throw the soil sideways as much as larger angles. However, narrower angles require longer blades.
- The crop gap, i.e. the space between the end of the blade and the crop plants / center of the intrarow. Generally, lower height blades require a smaller crop gap, so that the blades funnel soil to the center of the intrarow, and conversely, larger blades require a larger crop gap, so that there is a sufficiently wide base to support a larger ridge.
- Achieving sufficient depth control: as excess soil flows over the blades, it means ridgers have a reasonable tolerance to variations in operating depth, but, if they are too deep, they will no longer create a ridge, rather they will start tilling the soil, and if they are too high, they wont pick up sufficient soil to create a ridge. Some form of depth control is therefore required, typically a parallelogram or telescope system using a depth wheel, or mounted on another tool, e.g. a basket or brush weeder frame, or a pivoting system such as the bottom left image in Figure 2.

3.1.1. The pros and cons of mini-ridging for intrarow weed control

Mini ridging kill weeds entirely by burial, which differs from nearly all other mechanical weeding approaches such as horizontal blade hoes, finger, torsion and vertical spring tine weeders that kill by a mix of uprooting, severing / breaking as well as some burial. Mini-ridgers bury weeds considerably deeper and more consistently than other weeders. Ridging therefore has more in common with thermal weeding where all of the foliage is destroyed.

As weed death is caused by depriving the plants of light, it means that it is mostly unaffected by weather conditions compared with other mechanical weeders which require hot, dry, windy weather to maximise weed death.

Mini-ridgers also work across all soil textures (sand, silt and clays) and are highly tolerant of soil structure and stones. Exceptions are where soil crumbs are so coarse, or stones so numerous and large, it is hard to form a consistent ridge so light gets through to the buried weeds allowing them to continue to grow. Mini-ridgers will also work across a range of soil moistures from dry towards the plastic limit, as long as the soil will still flow rather than deforming.

Unlike most other intrarow weeders, where 100% week kill is the exception, mini-ridging has the ability to consistently achieve nearly 100% control of intrarow weeds. Critically this includes close-to-crop weeds (Nørremark & Griepentrog, 2004), which discriminatory intrarow weeders (Merfield, 2014), e.g., computer vision intrarow weeders, cannot kill, as the weeding tool is lethal to the crop plants so an unweeded 'safety zone' is left around the crop plants. Close-to-crop weeds are the ones that exert the most competition on the crop, due to their close proximity, so these are the most important weeds to control, but also the hardest, exactly because of their nearness to the crop plants.

As mini-ridging is gentle on crop plants because it pushes the soil sideways and upwards, it can be used on crop plants that would be killed, uprooted or damaged by other non-discriminatory intrarow weeders (Merfield, 2014), e.g., torsion and finger weeders.

Mini-ridging is also a great tool to use in combination with finger, torsion and vertical spring tine weeders as the former puts a soil mound up, and the latter, especially the vertical spring tine weeders, do a great job of pulling the mound down again, thus creating the classic potato ridge weeding technique of alternately pulling ridges up and down, but on a much smaller scale.

The key limitation with mini-ridgers is that there needs to be a sufficient size difference between the crop and the weeds, such that the weeds can be buried to a lethal depth while the crop remains above the ridge. That requires an understanding of what the lethal burial depth is and what the non-lethal partial burial depth is. However, there have been only a handful of research papers published on lethal burial depths.

3.1.2. Previous research

Terpstra & Kouwenhoven (1981) studied the impact of a Steketee 'hoe-ridger' in soil bins at uniform compaction. Garden cress (*Lepidium sativum*) was grown as a surrogate weed to two heights, 2.5-3 cm and 7-9 cm and very high densities of 3,000 plants/m^2. They found that when the soil moved sideways by the hoe was 2 cm deep it was lethal for most plants, with higher mortality for the smaller plants.

Jones *et al.*, (1995) studied the effects of a range of weeding treatments, including burial of intact plants at one and two centimetres on chickweed (*Stellaria media*), common poppy (*Papaver rhoeas*) at six true leaves and annual meadow grass (*Poa annua*) and rough meadow-grass (*Poa trivialis*) at three true leaves using John Innes No 2 potting compost which has a high soil content. At 2 cm burial the plants were partially buried leaving the growing point visible. At 2 cm burial chickweed had a 43% reduction in dry matter, poppy 38%, annual meadow grass 56% and rough meadow-grass 0%. At 1 cm burial chickweed had a 28% reduction, poppy 78%, annual meadow grass 88% and rough meadow-grass 59%.

Baerveldt & Ascard (1999) grew white mustard (*Sinapis alba*) at 2 days after emergence / 1.5 cm high and sentless mayweed (*Matricaria inodora*) at 1-2 cm tall and 2-3 cm tall, and buried them with a sandy loam at 0.5, 1.0, 2.0 and 3.0 cm, and then measured dry matter and plant numbers after eight days. For mustard, when the plants were incompletely covered with soil, all of them survived. At cotyledon stage, even when completely buried, "many plants grew through the soil layer" while at 0.5 cm of soil depth fresh weight increased, though plant numbers were unaffected. It took a soil depth of 3 cm to reduce plant numbers by half. For the larger mustard plants, plant numbers only decreased by about 8% at 3 cm soil depth, but dry matter halved. For mayweed, at the smaller size all plants were completely buried by 3 cm of soil which killed all plants, at 2 cm 90% of plants were completely covered, but, about 45% of plants survived. At the larger size, 95% of plants were covered at 3 cm soil depth and 5% survived, and at 2 cm depth 35% of plants were buried and 30% survived. At shallower soil depths all plants survived, and interestingly, there was a slight increase in dry weight, i.e., shallow burial increased plant growth. Baerveldt & Ascard (1999) also studied the effect of particle size using sand with grades 0.10, 0.55 and 0.90 mm, and found that survival increased with increasing particle size, which was hypothesized to be due to the finer sand being more compact and therefore having higher mechanical resistance and/or fine sand had lower light penetration.

Kurstjens & Kropff (2001) used perennial ryegrass (*Lolium perenne*) and garden cress, sown in soil bins and weeded with a spring tine harrow in the laboratory 3-4 days after emergence when the ryegrass had one thin leaf with an average height of 34 mm and the cress at early cotyledon stage with an average height of 12.5 mm. They found the critical burial depth to achieve plant mortality was 12 mm for ryegrass and 17 mm for the cress.

These studies indicate that burial under one to two centimetres of soil is lethal for a range of plants. However, the experiments using tine weeders have multiple impacts on the plants, e.g., bending, that may have also contributed to plant death and that would not occur in with ridging. Mostly small plants, e.g., <5 cm were studied, and while it is recommended to weed crops while the weeds are small, ideally at cotyledon stage, it would be valuable to determine if larger weeds can also be controlled. Also, most studies measured depth of soil from the planting substrate, and used average weed height to determine burial depth, meaning that the actual depth of soil for individual plants would vary from the mean, rather than directly measuring individual plant heights and then covering with specific soil depths in excess of plant height.

Further, none of the studies aimed to determine what the maximum depth of soil that ensures complete survival is, which is key to achieving selectivity, i.e., crop survival and weed death. Ridging is typically used on vegetables, often transplants that are significantly larger than the weeds, and large seeded row crops, e.g., maize, cotton, which is another reason to study the effect on larger plants. Due to the limitations in previous research, the Future Farming Centre undertook further studies to determine the lethal and non-lethal burial depths for a range of plants.

4. Lethal and non-lethal burial depths research trial

The research was conducted over three years with the methodology refined each year.

4.1. First and second years experiments

4.1.1. Methods

In the first year, five plant species mustard (*Sinapis alba*), white alyssum (*Lobularia maritima*), buckwheat (*Fagopyrum esculentum*), fescue grass (*Festuca arundinacea*), onion (*Allium cepa*), Californian poppy (*Eschscholzia californica*) were chosen to give a range of contrasting morphologies and be representative of range of crop and weed plants. Plants were grown in potting mix, in pots in a glasshouse (Figure 4). For each species 84 pots were sown at one time, with five seeds sown per pot. The plants were buried at four growth stages (seed, cotyledon, two and four true leaves), so were sequentially buried approximately one week apart depending on each species speed of growth. There were five burial depths, 0 (i.e., unburied control), 2, 3, 4, 6, 7 and 10 cm, achieved by placing a 10 cm dia. light proof, plastic pipe, of the given burial depth over the seeds or plants and carefully filling it with potting mix so as to leave the plant intact and standing in its original state. One week after the last set of plants had been buried, the pipe and compost was carefully removed from all pots, the number of surviving (i.e., still alive) plants was recorded, the plants were cut off at the hypocotyl and dry weight determined.

Figure 4. Second years experimental setup with rapeseed plants.

In the second year, rapeseed (*Brassica napus*) replaced mustard. Instead of sowing all plants of one species at one time, seeds were sown sequentially one week apart for each of the four growth stages, i.e., there were four sowing dates. Then, all plants were buried at the same time, i.e., the sequential burial used in the first year was replaced by sequential sowing in the second year. Plant growth stages did not therefore always exactly match the four stages listed for the first year's experiment due to different plant growth rates, both among and within species. At burial outstretched plant height (the highest / largest leaf was lifted vertically and height was measured to the leaf tip) which was averaged across all plants in each pot, and the number of plants buried per pot was recorded. Soil, a Templeton silty loam, replaced compost as the burial media, which was passed through a 10 mm sieve and then heated in an oven at 90°C for four days to kill weed seeds in the soil. After two weeks, the pipes and soil were carefully removed and number of surviving plants, and plant dry weight per pot were measured.

4.1.2. Results and discussion

4.1.2.1. Seeds vs. plants

The first years results for poppy most clearly showed the difference between burying seeds vs. emerged plants (Figure 5).

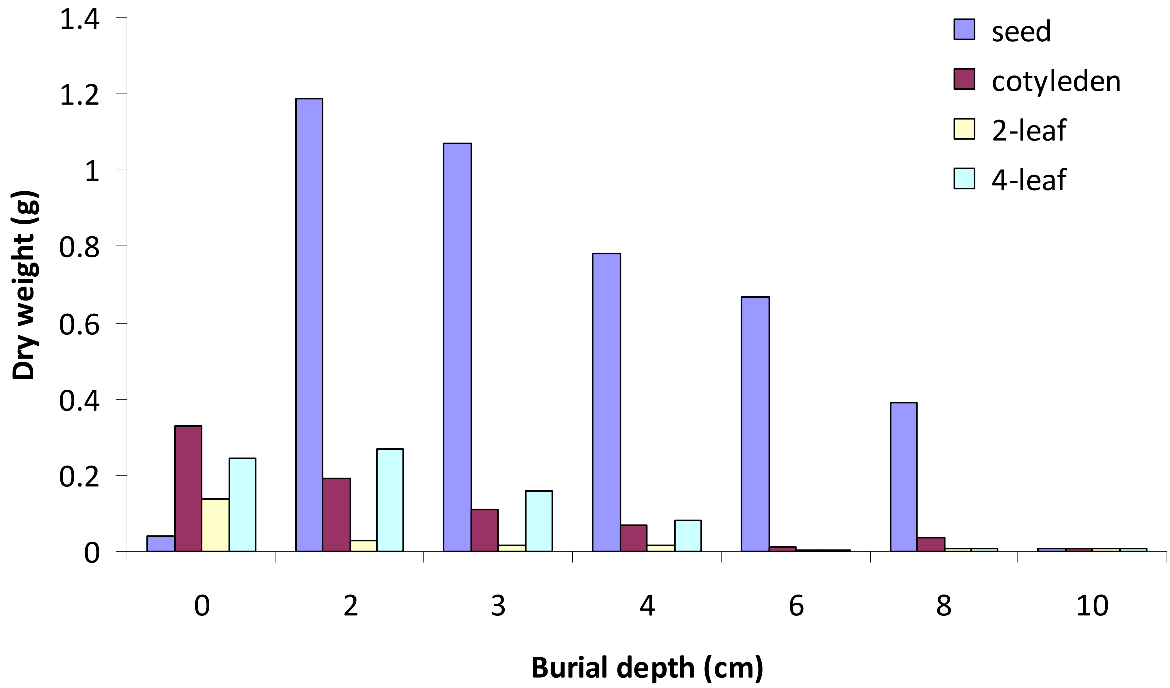

Figure 5. Dry weight of poppy plants that had been buried as seed or emerged plants at three growth stages. The low dry matter for zero burial depth was due to poor germination due to lack of seed covering.

There has been much research, especially in the first half of the 20th century, looking at the effect of burial depth on seed emergence, showing that emergence typically decreases linearly with increasing depth (Roberts, 1982). The previous research also found a simple physical relationship between the size / weight of a seed and the maximum depth of soil that the seedling can emerge from before it runs of either/or energy and nutrients stored in the seed (Figure 6).

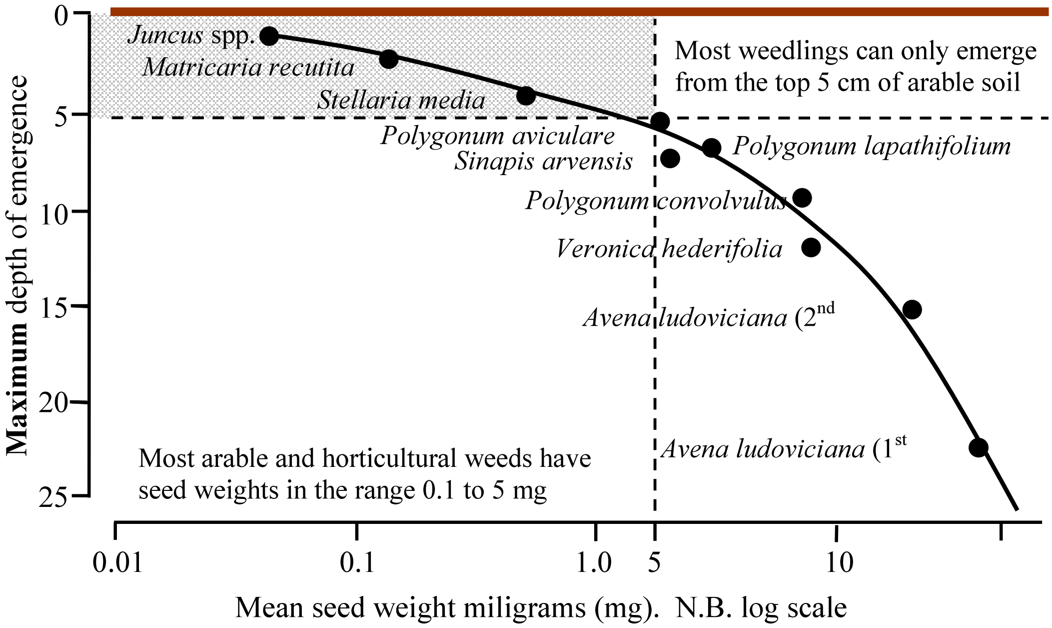

Figure 6. Maximum emergence depth of a range of weed seeds, After Roberts (1982).

4.1.2.2. The fallacy of weeding at the white thread stage

As evidenced by the poppy results, and previous research, unemerged seedlings can grow through several centimetres of soil, so weeding machines that rely on burial for a significant part of their weed control effect, will be less effective against seeds and unemerged seedlings, than waiting for the seedlings to emerge. Therefore, the belief that the best stage to weed is the white thread stage (i.e., between a seed germinating and the seedling emerging) is not correct, as the un-emerged seedling still has the ability to grow through the soil, so adding another centimetre or two of soil over a seedling already growing through the soil will have a limited impact on it emerging. A large amount of soil, e.g., greater than 4 cm, as evidenced by Figure 5, would reduce the number of emerged weeds, but, with the exception of mini-ridging, no current weeders achieve such burial depths.

4.1.2.3. Burying with soil vs. compost

The data for the first year did not achieve a clear result as plants survived burial at all depths, but, with a decline in dry matter as depth increased, as in Figure 5. Field experience across many crops and many years found that just a few centimetres of soil was sufficient to achieve excellent weed control. If the experiment matched field experience there should of been practically no weeds surviving greater than 4 cm burial depth, which was not the case, which indicated the methods were flawed. One hypothesis is that the potting mix the plants were buried with is much lighter than soil and the plants could push through it more easily. The second year's trial therefore used soil not potting mix for burial, and improved other aspects of the methods.

4.1.3. Second years results

However, the second years results were very similar to the first year. For each species the minimum burial depth that was required to achieve zero plant survival was determined (Figure 7).

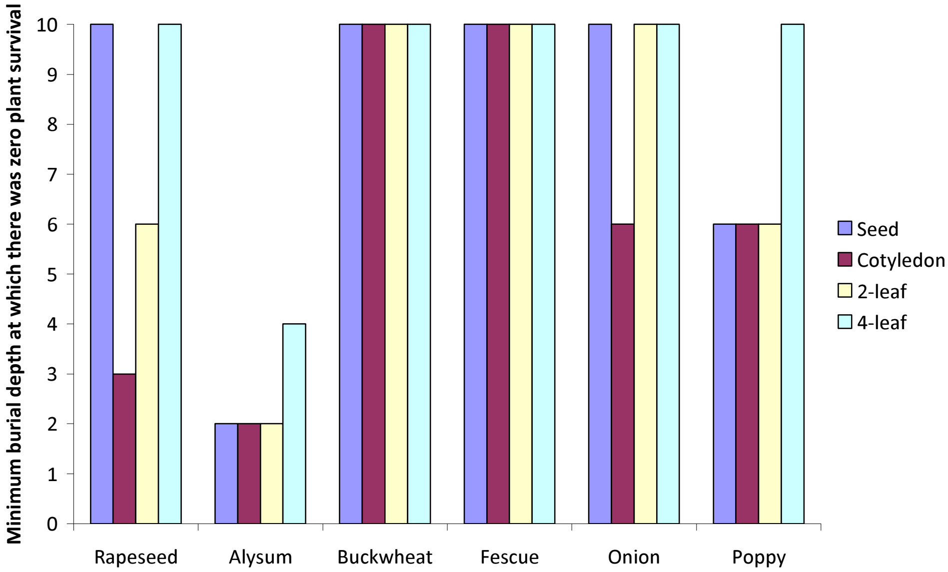

Figure 7. The minimum burial depth required to achieve 100% plant mortality.

However, with the exception of alyssum, all species had plants surviving burial at 10 cm depth, so there were clearly still methodological problems. It was realised that there was no direct relationship between burial depth and plant height. The data was reanalysed by subtracting the plant height from the burial depth, and calculating percentage survival by subtracting the number of plants surviving burial from the number that were buried and dividing that by the number of buried plants (Figure 8).

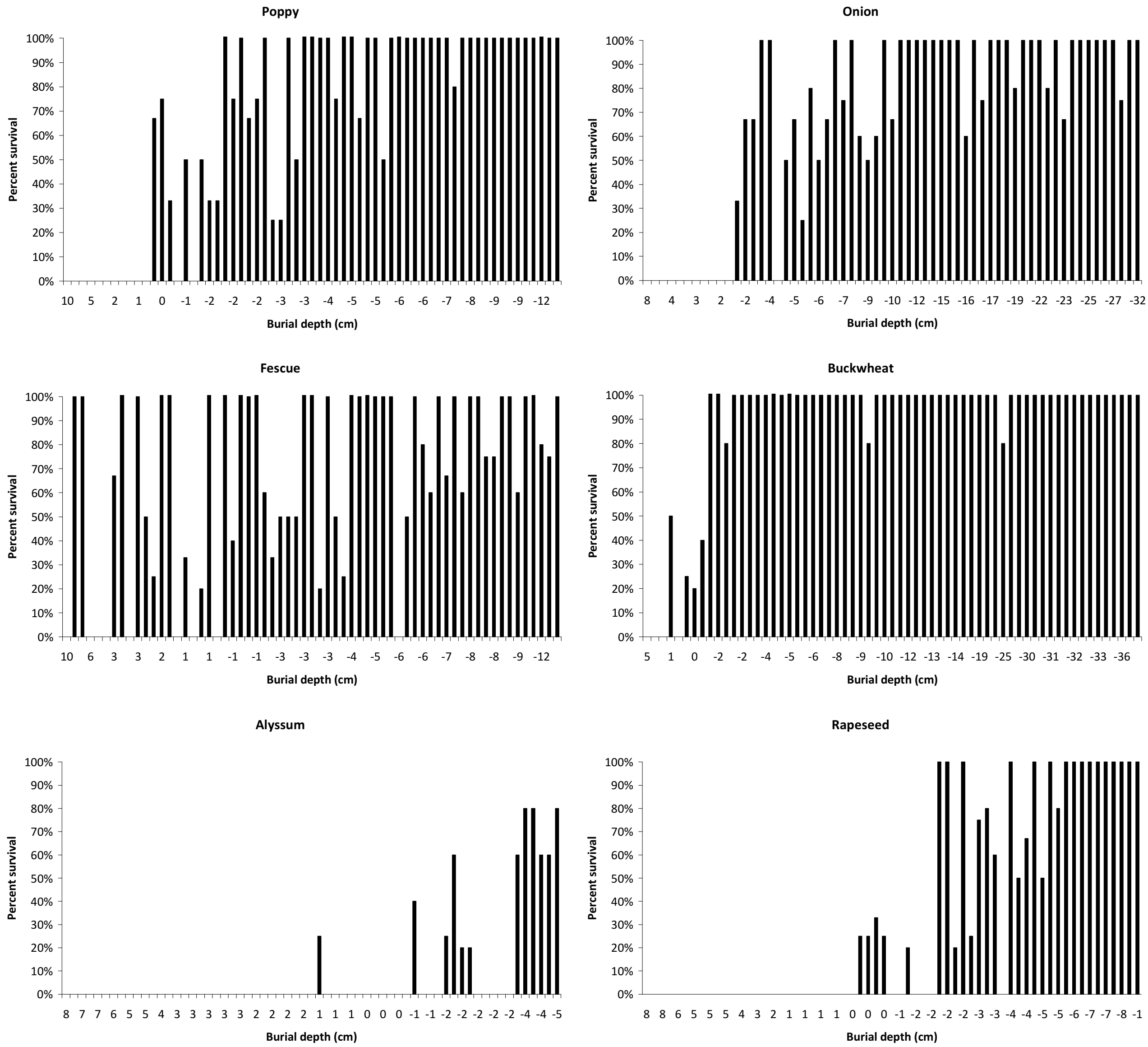

Figure 8. Relationship between survival of six plant species and depth of soil above plant height. A positive burial depth means soil depth was greater than plant height, i.e., plant was completely buried, a negative burial depth means plant height was greater than soil depth, i.e., the top of the plant was above the soil surface.

This clearly showed, with the exception of fescue, that when the plant height was less than depth of soil, i.e., the plant was completely buried, then plant survival was very low, often zero, but, as soon as plant high exceeded soil depth, then percent survival was very high, often 100%. However, as plant height was of the outstretched plant, which could be several centimetres higher than the in-situ height that was buried, and that height was averaged over all plants in the pot, there is potentially significant variance between individual in-situ plant height and depth of burial, so it cannot be considered rigorous enough to form the basis of on-farm decisions. However, re-analysis showed how the methodology needed to be changed.

The reason for fescue not showing the same pattern of high mortality when completely buried is unclear, but, it was theorised that as a monocotyledon, which produces leaves from the base, the growing leaves were able to push through the soil, and therefore allow the plant to continue to photosynthesise and therefore survive.

4.2. Third year

4.2.1. Methods

Six plant species, radish (*Raphanus sativus*) lucerne / alfalfa (*Medicago sativa*), carrot (*Daucus carota*), lettuce (*Lactuca sativa*), white alyssum, and perennial ryegrass (*Lolium perenne*), were chosen, again to represent a range of crop plant and weed morphologies. The plants were grown in pots, in potting mix, in a glasshouse. 108 pots were sown for each species, with a known number of seeds sown per pot, and then thinned to one plant prior to burial. There were five replicates. Plants were buried with 1 cm sieved, weed seed free soil, in three sequential stages aiming to bury plants at approximately cotyledon, two and four true leaves.

For each pot, the in-situ height of the plant was measured. Then a burial depth was randomly chosen. Burial depths ranged from -4 cm, i.e., the top of the plant was 4 cm above the top of the soil, to +6 cm, i.e., the top of the plant was 6 cm below the soil surface, and a null control where a pipe the same height as the plant was placed over the plant but it was not filled with soil. This was designed to represent both the weeds and the crop when the mini-ridgers are used in field, in that, the aim is to bury the weeds, but, leave part of the crop above the ridge. The range of burial depths varied with plant height with taller plants having a larger range of heights (Table 1).

Table 1. Burial depth range determined by plant height.

Plant height cm	Burial depths								Number of depths
1	Null	0	1	2	4				5
2	Null	-1	0	1	2	5			6
3	Null	-2	-1	0	1	2	5		7
4	Null	-3	-2	-1	0	2	4	6	8
5	Null	-4	-2	-1	0	2	4	6	8
6 and greater	Null	-4	-2	-1	0	2	4	6	8

Plants were buried for 21 days, and then surviving plants were counted.

4.2.2. Results

With the refined method, with burial depth directly related to individual plant height a very clear result was achieved (Figure 9).

The results for the six plant species were very similar, so their results have been averaged (Figure 9). Plant height was grouped into 10 mm bands (Figure 9), but, the results were the same irrespective of plant height, so, an overall average was also calculated (Figure 9). For burial depths of -2 cm, i.e., the plants were protruding from the soil by 2 cm or more, survival was 100% with the exception of one plant, that died despite a -4 cm burial. As burial depth reaches -1 cm (1 cm of plant protruding from the soil) survival rates start to rapidly decrease, 70% at -1 cm, 49% at 0 cm burial (the very top of the plant just visible at the soil surface) and 2% at +1 cm burial, with and average 4% survival for all positive burial depths (Figure 9).

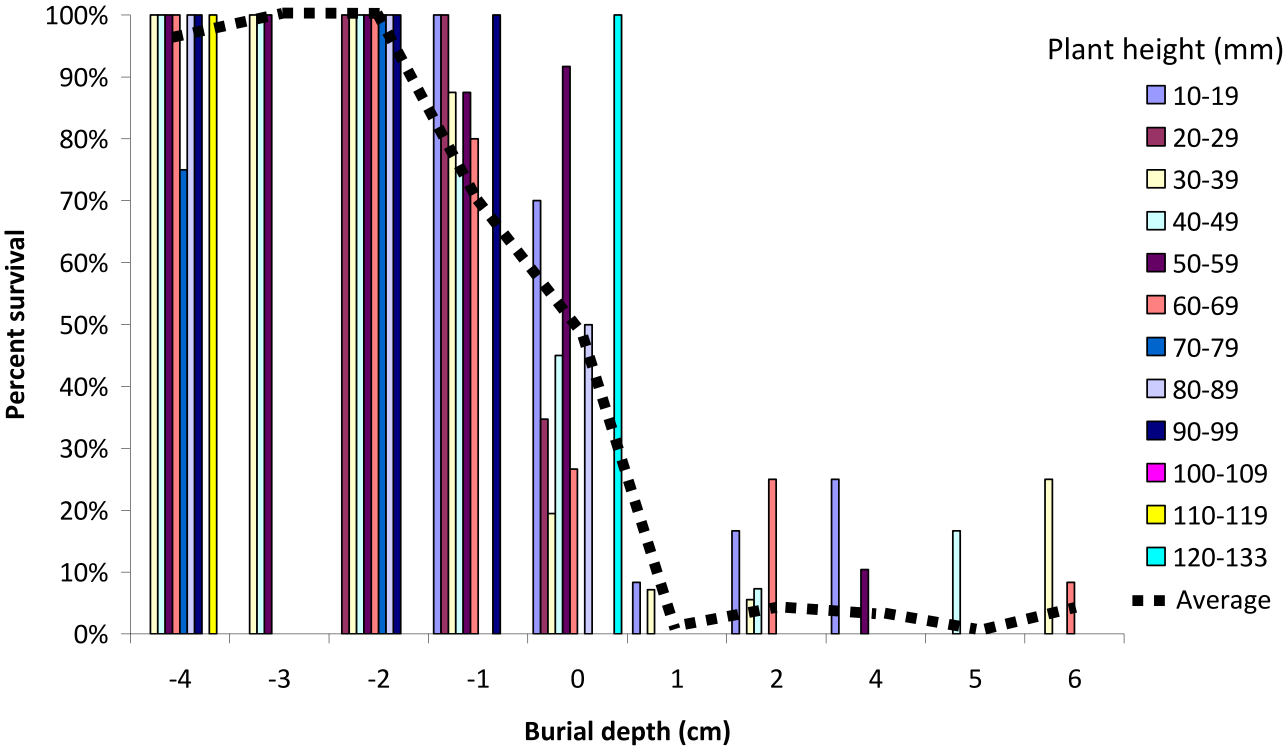

Figure 9. The effect of burial depth on average percentage survival of six plant species (radish, lucerne, carrot, lettuce, white alyssum, and perennial ryegrass), over a range of plant heights from 10 to 133 mm.

Burial is clearly a highly effective means of killing plants with just 1 cm soil depth able to achieve nearly 100% plant death. This is consistent with field experience, and also with previous research (Terpstra & Kouwenhoven, 1981; Jones *et al.*, 1995; Baerveldt & Ascard, 1999; Kurstjens & Kropff, 2001). Surprisingly, even partial burial is lethal, which, means some weed kill will be achieved even if burial is incomplete, but, it also means that the crop plant must have at least 2 cm protruding above the ridge otherwise crop plants will also be killed. The lack of effect of plant height is interesting as was expected that larger plants, which would have more stored resources, would be able to grow through greater depth of soil. Clearly this is not the case, with percent survival being similar for all plant heights (Figure 10), which is at variance with the results of Baerveldt & Ascard (1999). This means burial is just as effective against large as small plants, and that the ridge only needs to be big enough to just cover the weeds to kill them.

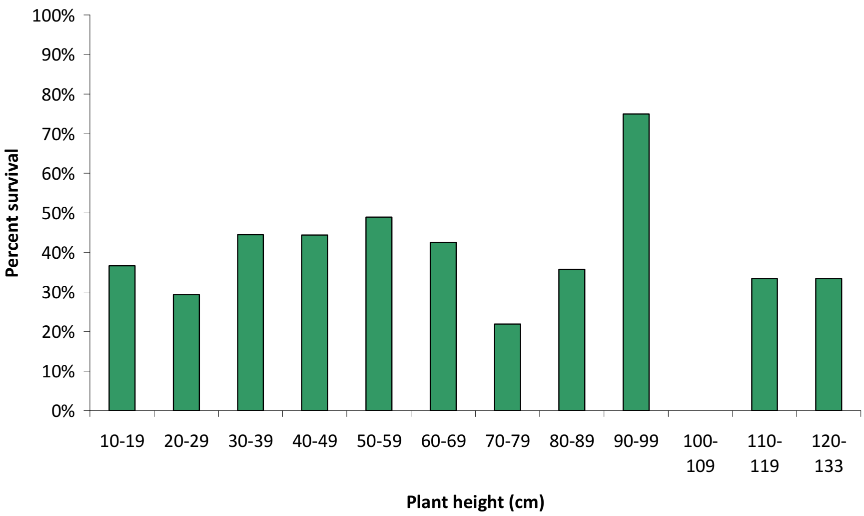

Figure 10. Average percent survival for each plant height band.

4.2.2.1. Ryegrass formation of secondary crowns

An interesting behaviour was noted in ryegrass on being buried, where the original crown, put out a shoot, that then developed into a second crown on reaching the soil surface (Figure 11)

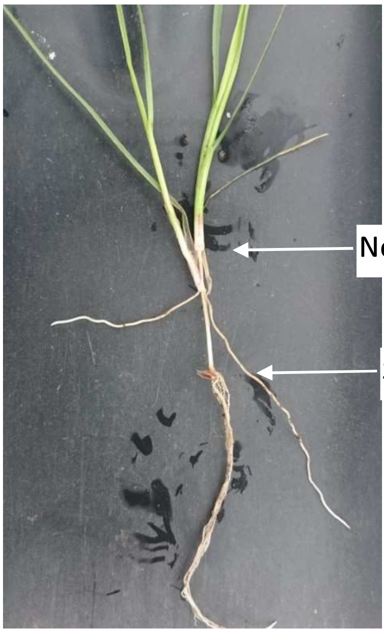

Figure 11. Secondary crown formation in ryegrass.

Only a few plants produced secondary crowns, so, survival in ryegrass was no greater than other species. However, if fescue is able to also produce secondary crowns, and does so in most individual plants, that may explain the much higher survival of completely buried fescue plants in the second years experiments (Figure 8).

4.2.2.2. Burial vs. thermal weeding

In section 3.1.1 mini-ridging was described as being more akin to flame weeding, in that the whole of the plants foliage is impacted and the effects are mostly weather independent. One use of flame weeders is post-crop emergence weeding, whereby crops that are 'resistant' to flaming due to their growing points being protected, e.g., onions and carrots, can be flamed to eliminate susceptible weeds, i.e., those that don't have protected growing points, e.g., fat hen (*Chenopodium album*) (Merfield, 2006). This process destroys the crop's foliage, but, it quickly regrows. However, in the second year of experiments, onion was one of the plants tested, and, when it was completely buried it did not survive (Figure 8), in contrast to flaming to which it is highly resistant (Dastgheib *et al.*, 2010). It therefore appears that while there are similarities between mini-ridging and thermal weeding, there are also some major and important differences in how crops respond to the two techniques, in that it appears leaving the foliage intact when buried fails to produce the same growth response seen when the foliage is destroyed by flame.

5. Conclusions

In terms of using mini-ridging in crops, this research indicates there is a simple rule of thumb to determine effectiveness: **Weeds must be covered by at least 1 cm of soil, the crop must protrude by at least 2 cm above the ridge, ideally a bit more, so there must therefore be at least 3 cm height difference between crop and weeds.** Where this is not possible, burial at 0 and -1 cm will still achieve medium levels of weed mortality, giving some benefit.

While the third years trial is considered a considerable success, it is only one pot trial on just six plant species, so ideally these results would to be validated in multiple field crops against a wide range of real weed species to ensure this rule of thumb is truly widely applicable.

6. Acknowledgments

Particular thanks to Jacque Bennett who undertook all the third year's, work intensive, experiments as well as helping with the second years experiment. Arthur Bluon, and Claire Berges, interns from France who helped with the second years experiments. Dr Nadine Keesing and Dr Dean O'Connell for their work on the first and second years trials respectively. Dr Simon Hodge for statistical advise. Brent Richards, Leona Meachen and other staff at Lincoln University nursery for looking after the experiments.

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