Final Report

Improving cultivation practices in potatoes to increase window of workability and soil structural stability

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1. SUMMARY

1.1. Aims of project

The aims of the project were to a) improve cultivation practices in potatoes, b) increase soil structural stability, c) lengthen the window of cultivatability and d) increase nitrogen (N) use efficiency.

1.2. Methodology

Fifty replicated-block experiments, mostly in commercial potato fields, were conducted on varying soil types over the period 2012-2014. Through manipulation of different cultivation machinery and depth of cultivation, these were designed to:

- Quantify the effects of organic matter (OM) content in soils on soil cultivatability, bulk density, strength, structural stability and aggregate size distribution.
- Quantify the effect of secondary cultivation machinery and depth of cultivation on tuber yield and quality.
- Measure the effects of contrasting ridge consolidation and profile on soil properties and crop performance.
- Quantify the effect of different cultivation techniques and depths on soil nitrogen supply (SNS) in soils with different texture and OM content.
- Produce a target for growers in terms of depth and physical parameters required within a seedbed to optimise marketable yield, quality and harvestability.
- Evaluate the costs of contrasting machinery and depths of cultivation used in producing beds for potatoes.

1.3. Key findings

On average, data from 16 experiments conducted in 2011-2014 with four to six destoner depths as a factor, showed that a significantly lower yield (50.5 ± 0.70 t/ha) was achieved when destoning 3-5 cm deeper than the commercial depth (53.4 t/ha). The yields from destoning at 22-28 cm (55.3 t/ha) were numerically greater than at the

commercial depth (typically 30-38 cm), although not significantly different but there was no evidence that destoning shallower than commercial depth resulted in lower yield. Whilst it might be expected that yields would be reduced in wet seasons by cultivating deeper (where soil would be expected to be wetter) owing to compaction, a positive effect on yield from destoning shallower than the commercial depth was not necessarily anticipated but was observed in all years of the project. In lighter soils (sandy loams), there was little statistical evidence that cultivating shallower altered yield but in heavier soils destoning shallower than the existing commercial depth increased yield.

Where soils have sufficient clay content to have a plastic limit (PL), growers should be aware that the critical cultivation depth in most springs would be shallow enough to cause issues of compaction, even by cultivating at the standard depths used by the industry. They should also be aware, that owing to alterations in previous cropping, rainfall and irrigation patterns and previous trafficking and cultivation regimes will alter the critical cultivation depth, even in the same field. Using data from EC scans conducted when soils are at field capacity, soil texture, organic matter and Keller & Dexter (2012) to calculate the PL variation across a field, a zonal map of critical destoning depth can be constructed which would highlight critical areas in the field and make cultivation more effective, irrespective of the crop.

It was easy to achieve the grower's target planting depth despite variation in depth of beds. Shallow destoning did not affect planting depth or time from planting to emergence, however there was greater variation in planting depth and emergence in soil destoned deeper than commercial practice, particularly on heavy soils. On heavy sites, in general, working soil excessively deeply resulted in insufficient differential between the clod compacted into the wheelings between beds and the top of the finished bed, which resulted in difficulty obtaining sufficient soil to form ridges or the planter riding up out of the bed. This combination made it difficult to achieve consistent planting depth and it tended to be shallower than targeted.

Whilst most sites showed no effect of destoning depth on tuber bruising following commercial harvesting, there were experiments, particularly on very stony soils, where the overall incidence of bruising was high and where bruising was significantly increased by destoning shallower than 35 cm. However, once the harvester share had been raised to account for the shallower bed, bruising became similar across all destoning depths but there was still a directional trend for shallow destoning to result in more bruising. This indicates careful consideration to destoning depth is required in very stony areas of fields but the whole field should not be destoned as deeply if the other areas are less stony. Harvester operators would have to pay closer attention to depth but variable depth destoning would benefit yield and soil structure.

The difficulty in producing a clod-free seedbed from traditional working depths on heavier soils which are close to their plastic limit may be significantly reduced by bedforming and destoning 3-5 cm shallower than many growers currently do and this presents few risks to productivity or quality. Tuber quality (common scab, cracking and greening) was not affected by destoning depth.

There were significant savings in fuel (£6-11/ha) from cultivating beds shallower than current commercial depths but the cost saving per tonne of harvested tubers was small (*c*. 10-20 p/tonne). An overall improvement in rate of work of *c*. 40 % was achieved by destoning 9 cm shallower than the commercial depth (average 33 cm), which speeds up what is often the rate-determining step in the planting operation. At a depth more suitable for commercial production and safe harvesting (27-28 cm), the rate of work was still 19 % faster than the current commercial rate. More importantly, shallower destoning gives greater opportunity for soils to be cultivated closer to their optimum soil water content as well as reducing the wear on machinery and lowering labour costs.

Soil density in the upper 12 cm of the ridge increased during the season as ridges consolidated owing to natural weathering and gravitational settling and through slumping from rainfall and irrigation. This resulted in a corresponding decrease in ridge porosity through collapse of larger pores and creation of smaller peds within the ridge. In overly-fine structured soils, this reduction in porosity during the season would be great enough to cause problems with drainage during wet periods close to, or during, harvest. Over-working soils by destoning at depths >30 cm typically resulted in more loose soil within the ridge at planting but by harvest this extra porosity had been lost and soils were more dense that where destoning was carried out at shallower depths. However, the effects of destoning depth on the changes in ridge density varied between seasons: in some years there was no effect and in others, deeper destoning resulted in greater changes in density than shallower destoning. There were small benefits in reduced soil resistance and bulk density resulting from destoning more deeply, however these did not translate into improvements in yield or quality.

Perhaps contrary to perceived views, very shallow destoning (e.g. < 25 cm depth) on heavy soils (>20 % clay content) resulted in ridges composed of smaller peds with fewer very large (>35 mm diameter) peds than ridges created from soil destoned deeper than *c*. 35 cm. Working soils close to, or above, their plastic limit resulted in clod formation which was left in the ridge rather than being deposited in the wheeled furrows.

The data from the series of 14 experiments (including one from 2011) involving N application rate and cultivation depth indicated that the SNS of many potato soils is underestimated by the current index system and this, in part, may be due to the intensity of the cultivation used to create potato seed beds. However, the apparent lack of effect of depth of destoning on SMN and crop N uptake is of interest and may be due to most OM being in the top 25 cm of the soil profile. Therefore, when compared to shallow cultivation, deep cultivations do not expose significantly more OM to oxidation and the subsequent release of inorganic N.

1.4. Practical recommendations

Soil should not be cultivated deeper than is necessary to produce destoned beds of *c*. 27-28 cm in depth prior to planting. Although it is recognised that processing crops require less finely-structured soil owing to the reduced importance of common scab, soil is routinely cultivated deeper and more aggressively than is required for growing high yields of packing quality potatoes.

Destoning deeper than 35 cm on sandy soils and deeper than 28 cm on heavy soils will result in reduced yields. However, destoning to 27-28 cm on sandy soils when it is common practice destone to 35-38 cm can **increase** yield by *c*. 1.8 t/ha. On heavier soils, the penalty for cultivating below the critical depth can be greater (i.e. 3-5 t/ha), so destoned beds as shallow as 22-24 cm can result in improved yields and yet still provide sufficient soil to plant and harvest tubers with minimal damage.

Destoner operators should receive training so that all beds are produced to similar depth which would aid accurate planting (depth and spacing). It was frequently observed that two, three or four identical destoners following one another in adjacent beds frequently produced beds of significantly different depth depending on the operator and tractor used.

Producing beds as shallow as 25 cm will not affect planting depth or time from planting to emergence. However, there is likely to be a greater variation in planting depth and emergence in soil destoned deeper than the critical depth for cultivation, particularly on heavy soils, owing to inadequate differential between wheelings and the top of the finished bed which leads to poor planter performance.

Destoning to produce beds at 27-28 cm gives greater opportunity for soils to be cultivated closer to their optimum soil water content. The difficulty in producing a clod-free seedbed from traditional working depths on heavier soils which are close to their plastic limit may be significantly reduced by bedforming and destoning shallower than many growers currently do and this presents few risks to productivity or quality. In wet springs when planting can be delayed well into May, thereby incurring a yield loss owing to a truncated growing period, the ability to travel 20% faster with shallower destoning could have a much larger effect on yield.

By gradually increasing the depth of destoning on heavier soils, operators would be able to observe the sudden change in soil being placed in the furrow and this would indicated that they were close to the critical depth for cultivation. On heavier soils, a good correlation was observed between the critical depth for destoning as measured by the plastic limit and the quantity of soil (not stone) being deposited in the furrow having failed to be worked into aggregates of suitable size.

Seedbeds can be made appreciably coarser and shallower than current practice before any significantly increased risk of common scab or greening. Tuber quality (common scab, cracking and greening) is largely not affected by destoning depth, aggressiveness of destoning or type of destoning machine. Where areas of fields contain high or very high stone content, destoning depth may have to be deeper to avoid bruising but closer attention to harvesting depth will reduce tuber damage.

Shallower destoning reduces the wear on machinery and results in lower repair and depreciation costs and decreases the chance of breakdown during the

planting season. Averaged over 10 years following the purchase of a new star destoner, for standard commercial depth destoning (34 cm) on stony, sandy soil, the cost of destoner repairs and parts have been calculated at *c*. £2.49/t (£142/ha) out of a total cost for depreciation, fuel, labour, finance and insurance of £4.41/t (£248). Reducing the depth of destoning to 28 cm reduced the total cost to £3.77/t (£213/ha), of which repairs and parts contribute £2.05/t (£117/ha). Reduced fuel, labour and repairs and parts of shallower destoning contribute 7, 11 and 44 p/t cost savings, respectively.

Large savings in labour costs can be made through faster work rates. An overall improvement in rate of work of *c*. 20-40 % is achieved by destoning 5-9 cm shallower than the current standard commercial depths, which speeds up what is often the rate-determining step in the planting operation.

Significant savings in fuel (e.g. £6-11/ha) can be made by destoning beds shallower than is currently being practiced. However, the cost saving per tonne of harvested tubers is relatively small (*c*. 10-20 p/tonne) and should not be put forward as a major reason to cultivate shallower. Nevertheless, producing deep beds for destoning requires deep cultivation and this is where similar savings in fuel can be made, of the order of 50 %, worth another £5-10/ha (10-20 p/tonne). The whole system of shallower beds needs to be matched to overall shallower primary cultivation to achieve the most effective cost savings and benefits to soil and crop performance.

If very stony areas exist in fields, careful consideration to destoning depth is required to avoid bruising and mechanical damage to tubers but the rest of field should not be destoned as deeply if less stony areas exist. Harvester operators would have to pay closer attention to depth but variable depth destoning would benefit yield and soil structure.

The SNS used to determine N requirements should not be adjusted for the depth of cultivation but it should be recognised that the current system underestimates the SNS of many potato soils and this, in part, may be due to the intensity of the cultivation used to create potato seed beds. Despite working a bigger volume of soil, destoning deeper does not liberate more N from the soil and no changes in N fertilizer recommendations are needed for different secondary cultivations.

2. INTRODUCTION

Potato Council-funded work in 2007-2010 showed that the relationships between soil bulk density, organic matter and water content at cultivation obtained from commercial fields can guide the suitability to cultivate but a single relationship between these parameters is unlikely to be universal as there is significant field-to-field and within-field variation in the cultivation window. Soil organic matter content was negatively correlated with the bulk density at cultivation depth, suggesting that even small improvements in organic status on mineral soils with low organic carbon content would improve cultivatability. Cultivating soil above its plastic limit resulted in a consistent 7-17 % increase in bulk density compared with cultivating drier soil but yield losses were not related to the increase in bulk density. Yield losses associated with cultivating soils at inappropriate moisture contents do not necessarily result in large yield loss if the season that follows is relatively benign in terms of drought or heat stress or low radiation levels which result in slow rates of growth. However, where conditions were very favourable for rapid growth following emergence, the compromised water uptake of crops growing in compacted soil resulted in restricted canopy growth and yield, even where irrigation was applied.

Mean clod size within the ridge decreased during the season as the soil weathered and lost structure but the degradation was only slight indicating that cloddy ridges at planting are likely to remain cloddy through to harvest and a balance needs to be drawn between soil which is too wet at depth to cultivate, yet sufficiently moist on the surface to break down to a fine structure during ridge formation. This project was conducted to provide better quantitative relationships between the cultivatability, organic matter, depth of cultivation and wetness of soil and crop yield and quality responses.

An initial study prior to this project was conducted in 2011 when the planting season was very dry and all sites were easily cultivated. Increasing destoning depth from 20 to 50 cm depth increased the volume of low density and low strength soil, which would be expected to appreciably improve rooting depth owing to faster root elongation between 20 and 50 cm. Uniform planting depth was achieved even in shallow beds and there was no indication that more shearing compaction occurred in deeply-destoned soil at the share-soil interface than with shallow-destoned soil. Depth or aggressiveness of destoning did not affect any measured plant growth variate (tuber yield, quality or bruising). However, shallower destoning clearly has the potential to improve work rates, thereby lengthening the window to cultivate soil at the optimum soil water content. Additionally, there are other savings in costs (e.g. labour, fuel and spares, repairs and depreciation on specialist equipment). The work in the project reported here was conducted to further test the relationships between cultivation depth, soil parameters, crop yield and quality and costs of cultivation.

Earlier Potato Council-funded projects (e.g. R273 and R405) concentrated on understanding some of the factors that limit N uptake by potato crops and the relationship between N uptake, canopy persistence and yield. Data from these projects, and others, showed that total N uptake in crops receiving no N fertilizer was very variable even in soils that had similar textures, amounts of organic matter and previous cropping history. Furthermore, total N uptake was often much more than would be expected from estimation of SNS on the basis of soil texture and previous cropping. If it is assumed that crop N uptake is similar to SNS, then this variation will be responsible for modifying a crop's response to inorganic fertilizer and thus make accurate prediction of fertilizer requirement difficult. It is probable that some of the variation in crop N uptake is not only due to variation in the amount of inorganic N in the soil but also due to soil conditions (e.g. compaction, cloddiness etc.) within the seedbed. The objective of this part of the project was to measure soil mineral N and N uptake in crops grown in beds cultivated to contrasting depths to determine any differences resulting from the treatments and the practical consequences for N requirements.

3. Materials and methods

3.1. 2012

In 2012, there were eight experiments conducted on sites in Norfolk, Essex, Lincolnshire and Suffolk investigating the effect of bed depth and sieving aggressiveness on soil parameters and crop yield and quality. There were also three experiments at Cambridge University Farm (CUF) and in Suffolk examining depth of cultivation and nitrogen (N) rate. There was an additional experiment in Norfolk examining planter profile. There were, in addition, a number of simple comparisons in commercial fields examining the effects of destoning depth and aggressiveness on tuber yield and crop quality.

Between September 2011 and March 2012, 20 fields were surveyed using electrical conductance (EC) scanning by either, or occasionally both, SOYL (Dualem 1S machine) and SoilQuest (Veris 3100 machine) on a grid pattern of 12 m centres to two depths (30 and 90 cm). This type of scanning relates the electrical output to soil water content which is largely a function of soil texture and, to a lesser extent, soil compaction. The resulting EC images were used to select suitable fields where there was significant variation in apparent water content. To cover the contingency of being able to visit sites when they were being planted, two fields were selected from each grower group and two areas (20 m in width and 120 m in length) of contrasting soil identified in each field for detailed experiments. These were referred to as 'light' i.e. sandier soils or 'heavy' i.e. higher clay content soils. Eventually, only six fields were selected for detailed experiments, with the other fields used for simpler destoner treatment comparisons or not used.

The list and basic cultivation details of the experiments conducted in 2012 are given in Table 1 and the soil and seed details in Table 2. The locations of Expts 2012-1 to 2012-11 are shown on the EC maps in the Appendix (p. 149).

Table 1. 2012: List of experiments and basic cultivation details

Expt	Location	Grower	Field	Cultivated	Treatment	Depths	Tractor-Machine†
2012-1	Raveningham, Norfolk	Greenvale AP	Norton Road	26 Mar	Destoner depth	6	JD6930 CS170
2012-2	Raveningham, Norfolk	Greenvale AP	Norton Road	26 Mar	Destoner depth	6	JD6930 CS170
2012-3	Tuttington, Norfolk	LF Papworth Ltd	Bungalow	28 Mar	Destoner depth	6	NHT7.200 CS150
2012-4	Tuttington, Norfolk	LF Papworth Ltd	Bungalow	28 Mar	Destoner depth	6	NHT7.200 CS150
2012-5	Thornham, Norfolk	Spearhead Marketing Ltd	Bakers 1	30 Mar	Destoner depth	6	JD6930 CS150
2012-6	Thornham, Norfolk	Spearhead Marketing Ltd	Bakers 1	30 Mar	Destoner depth	6	JD6930 CS150
2012-7	Fyfield, Essex	Stevenson Bros	Harriets	11 Apr	Destoner depth	6	JD6930 Megastar Gen-2
2012-8	Holbeach Hurn, Lincolnshire	AH Worth Ltd	Field 17	18 May	Subsoiling x bedtilling	2	Challenger AVR
2012-9	Knettishall, Suffolk	Spearhead Marketing Ltd	Buchers Barn	22 May	Destoner depth x N	2	JD6930 CS150
2012-10	Cambridge, Cambridgeshire	Cambridge University Farm	Cage Side	12 Apr	Bedtiller depth x N	2	MF575 Howard / MF 2480 Rumptstad
2012-11	Cambridge, Cambridgeshire	Cambridge University Farm	Cage Side	12 Apr	Bedtiller depth x N	2	MF575 Howard / MF 2480 Rumptstad
2012-12	Burgh St Peter, Norfolk	Greenseed International	Banns	29 May	Profile x tilth x hood pressure	-	JD6930 CS150

†JD = John Deere; NH = New Holland; MF = Massey Ferguson; CS = Grimme Combistar; Megastar = Standen Pearson Megastar; Challenger = Caterpillar Challenger; AVR = AVR rototiller; Howard Rumptstad = Rumptstad rototiller.

Table 2. 2012: Seed and soil details

Expt	Variety	Soil texture	Sand (%)	Silt (%)	Clay (%)	OM (%)	Seed size (mm)	Seed spacing (cm)
2012-1	Maris Piper	Sandy loam	64	22	14	1.9	30-40	91 x 28
2012-2	Maris Piper	Sandy clay loam	58	23	19	1.5	30-40	91 x 28
2012-3	Saturna	Sandy loam	60	25	15	2.3	45-55	91 x 36
2012-4	Saturna	Sandy silt loam	48	35	17	1.8	45-55	91 x 36
2012-5	Lady Rosetta	Sandy clay loam	59	18	24	1.5	40-50	91 x 31
2012-6	Lady Rosetta	Sandy clay loam	51	20	29	1.5	40-50	91 x 31
2012-7	Desiree	Clay	17	40	43	4.4	35-45	91 x 25
2012-8	Melody	Clay loam	29	49	22	2.5	45-55	91 x 45
2012-9	Lady Rosetta	Sandy loam	65	22	14	1.3	35-40	91 x 23
2012-10	Maris Piper	Sandy loam	69	18	13	3.2	30-40	76 x 30
2012-11	Maris Piper	Sandy clay loam	58	19	23	4.0	30-40	76 x 30
2012-12	Annabelle	Sandy loam	59	25	16	1.6	35-40	61 x 27

3.1.1. Cultivation depth experiments

Experiments 2012-1 to 2012-7 were all of the same randomised block design with four replicates of six treatments but with different randomisation. The treatments were six depths of destoning, with the actual depths for each experiment being determined during a calibration procedure. There were two depths shallower than standard commercial depth used in the field and three depths deeper than standard. The intended and actual depths achieved are detailed in the Results section. Deep beds were produced to the grower's specifications for their standard depth of destoning (generally 34-36 cm but 25 cm on one site) but there was little difficulty destoning to deeper depths as the beds were deeper than required for the standard depth. Drivers of machines were asked to destone a section of bed close to each experiment at their normal depth, forward speed, star spacing and agitation settings and these were recorded. A calibration was then performed by setting the destoner on manual depth control, then varying the depth of penetration of the machine and recording the finished depth of bed. This was done by inserting a fibreglass flexicane with measurements marked on it into the bed until the cultivation layer was felt. This was repeated over six-eight depth increments. With the deepest treatments, the destoner was allowed to penetrate as deep as the machine and bed height would allow or just prior to the destoner blocking up with excessive soil load on the webs. The chart produced between finished bed depth and share depth was then used to select the depths of destoning varying in 5 cm increments where possible but on sites where the commercial depth was shallow (i.e. 25 cm), then increments were *c*. 3 cm. The forward speed was then adjusted to a set value and the depth and star spacing altered to suit the treatment being applied. Operators were asked to load the machines with soil to similar levels and adjust the forward speed to maintain the soil load on the webs through different depth treatments. Spot rates of forward speed and fuel consumption were measured using the tractor's on-board computer, with at least four readings of each variable in both directions of travel being taken per plot, to take account of any variations in soil or slope. Following destoning, the depth of the finished bed was measured prior to planting so that comparisons could be made with the intended depths. This was done in five random positions (i.e. left, centre and right of bed) in each of two beds in the centre of each plot and the mean bed depth recorded. Plots were two beds (four rows) wide and 20 m long to accommodate changes in soil load between different plots resulting from contrasting depths of destoning. The central two rows and the middle 5 m of each plot were used for plant and soil measurements.

The experimental design in Expt 2012-8 was a factorial combination of two subsoiling and two depth treatments with six replicates. The two subsoiling treatments consisted of either flat-lifted in autumn 2011 or not subsoiled. The subsoiling treatments were laid out in six replicated strips across the field. The depth treatments were rototilling at 18 cm (Shallow) or 28 cm (Deep). The standard rototilling depth in the surrounding field was 23 cm. The depth treatments were superimposed on top of the subsoil treatments at planting.

3.1.2. Nitrogen x cultivation depth experiments

The experimental design in Expt 2012-9 was a factorial combination of two depths of destoning and two rates of N fertilizer. The Shallow plots were destoned at 22 cm and Deep to 48 cm. The N treatments were applied using a Horstine Farmery band applicator mounted on the planter. The rate of urea fertilizer (46 % N) was adjusted to give a rate of 200 kg N/ha for 200 N plots and incorporated into the bed in front of the opening shares. The applicator was turned off for 0 N treatments. Each plot was 20 m long and four rows wide and there were six replicates.

Experiments 2012-10 and 2012-11 were conducted at Cambridge University Farm, Cambridgeshire and were split-plot designs with cultivation depth as main-plot and N level as split-plots with four replicates. Two areas of the field were selected which had contrasting soil texture. Both areas were ploughed on 21 March. There were two nitrogen rates (0, 200 kg N/ha applied as ammonium nitrate prills), which were applied to ploughed soils immediately prior to the cultivation treatments. Two different cultivation depths were used: shallow, achieved by rotavating to 15 cm depth using a Howard Rotavator and deep, achieved by rotavating to 25 cm using a Rumptstad Rototiller. The flat soil surface remaining after rotary cultivation was ridged using a Cousins fixed-share ridger.

3.1.3. Planter profile experiments

The experimental design in Expt 2012-12 was a factorial combination of two degrees of aggressiveness of destoning (Fine, Cloddy), two bed profiles (Flat, Ridges) and two planter ridge hood pressures (Zero, Maximum). The 'Fine' treatments were achieved by fully closing the stars on the destoner, running the P.T.O. at 424 r.p.m. and travelling at 1.0 km/h. The 'Coarse' treatments were achieved by fully opening the stars on the destoner, running the P.T.O. at 370 r.p.m. and travelling at 2.0 km/h. Each plot was 20 m long and two beds wide and there were three replicates.

3.1.4. General methodology

The soil water content in bedformed (Expts 2012-1 to 2012-7) or flat-profile cultivated (Expts 2012-8, 2012-10 and 2012-11) soil was measured immediately prior to destoning or cultivating using a Delta-T Devices Theta Probe. Measurements were taken in all plots of the experiment by excavating a pit to 40-60 cm depth from one wheeling and measuring the mean water content in three walls of the pit at 5 cm depth intervals. In Expts 2012-1 to 2012-6, the depth range was 25-55 cm and in Expt 2012-7 15-45 cm. In Expt 2012-8, the flat soil surface left by primary cultivation was used as the reference height and the measurement range was 15-30 cm. In Expts 2012-10 and 2012-11, the soil water content was measured at a depth of 15 and 25 cm from a flat, ploughed surface.

On eight commercial sites in Norfolk and Essex (including areas adjacent to Expts 2012-1, 2012-2, 2012-7 and 2012-12), simple comparisons with 4-5 replicates were made between shallow, standard and deep destoning or fine versus coarse grading using destoners. These were assessed for yield and tuber quality only. Five of the sites were Maris Piper, two were Desiree and one was Annabelle.

Estimates of the quantity of clod and stone removed into the furrow during destoning in Expts 2012-5 to 2012-7 and were made by placing plastic crates (56 x 37 x 30 cm) in the furrow bottoms of adjacent beds to catch the stones and clods. Two replicates per plot were taken, one from each bed. These were combined and weighed.

Plant emergence was recorded every 2-3 days in each plot by counting the number of plants emerged in two harvest rows. Planting depth was estimated by measuring the length of a below-ground stem from five random plants in each plot after full plant emergence. Ground cover in the two harvest rows was measured using a grid at weekly intervals after emergence. A final harvest of 3 m from a single row (1.5 m x three rows in Expt 2012-12 and Expt 2014-4) was taken in July-October when the crop was ready for commercial harvesting. The tubers were graded, counted and weighed in 10 mm increments. A representative sample of tubers weighing *c*. 500 g was dried at 90 °C for 48 h to measure tuber dry matter concentration ([DM]). Fifty tubers were assessed for incidence and severity (% surface area (SA) infected) of common scab in the categories of 0, 0-1, 2-5, 5-10 % SA and then in 10 % increments. Tubers were also assessed for type, incidence and severity of tuber cracking, greening and other growth defects at final harvest. All experiments except Expt 2012-8 were irrigated according to the Cambridge University Farm Potato Irrigation Scheduling model.

The dry bulk density of the soil was measured at 22.5, 27.5, 32.5, 37.5, 42.5 and 47.5 cm (mean depth) by digging a profile pit into the side of the ridge, inserting two stainless steel soil sampling rings (5 cm diameter x 5 cm depth) into the centre of the ridge and excavating soil carefully from around the ring using a small builder’s trowel. Where the ring could not be pushed into the soil using hand pressure on the back of the trowel, it was forced into the soil using a steel plate and hammer. Care was taken to ensure that the rim of the sampling ring was flush with the soil surface. The ring was sealed with a plastic lid, undercut with a trowel and the trowel pushed underneath to extract the core. The outside of the ring was cleaned of excess soil and the sample was pushed into a plastic bag and sealed. The soil sample was weighed then dried for 24 h at 105 °C in a re-circulating oven. Porosity was determined from dry bulk density, water content and an assumed particle density of 2.65 g/cm^3 (Hall *et al*. 1977).

Soil resistance readings were taken using an Eijkelkamp Penetrograph penetrometer (1 cm^2 60° cone tip) in the centre of the ridge to a depth of 50 cm immediately following planting. Three replicate readings of resistance were taken in each plot of all experiments.

Ped size distribution was measured by grading a large-volume (2.0 l) soil sample taken only at final harvest. After removing 1 cm of soil from the apex of the ridge, a 20 x 10 x 10 cm deep steel box was pushed into the centre of the ridge mid-way between two plants and extracted by sliding a flat plate underneath and excavating soil with a spade. The soil was transferred to a plastic bag which was then weighed and sealed. At a subsequent date, the sample was carefully tipped into aluminium trays and dried at 105 °C for 24 h, then reweighed and sieved into ten grades (< 2, 2-6, 6-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40 and 40-45 mm) using a combination of potato riddle grids and Endacott soil sieves. The soil in each grade was weighed and the weight fractions in each grade calculated.

In Expt 2012-9, soil sample cores were taken on 20 June and 28 August using a 55 mm internal diameter, ‘Dutch’ type auger. Each core was split into three depths (0-30, 30-60 and 60-90 cm) and cores were taken from three positions across the bed. Core ‘A’ was taken from the centre of the bed, core ‘B’ was taken between adjacent plants within the row and core ‘C’ was taken from the wheeling. A random selection of three replicates (of the possible six) of unfertilized, shallow or deep cultivated plots was sampled (18 cores in total). The cores were placed in polythene bags and kept in a cool-box together with ice-packs before being dispatched by courier within 24 h of sampling to Natural Resource Management Ltd for analysis for soil mineral N (SMN). Foliage from each plot at the final harvest was weighed, sub-sampled to *c.* 1 kg and dried. Dried haulm and tuber samples were analysed for total N content at NRM Ltd.

3.2. 2013

In 2013 there were 19 experiments conducted on sites in Cambridgeshire, Essex, Norfolk, Shropshire, Somerset and Suffolk investigating the effect of bed depth and sieving aggressiveness on soil parameters, crop yield and quality and harvesting damage. During September 2012-April 2013, 23 fields were surveyed using EC scanning. To cover the contingency of not being able to visit sites when they were being planted or other reasons, more fields were EC-scanned than required.

The list and basic cultivation details of the experiments conducted in 2013 are given in Table 3 and seed and soil details in Table 4. The locations of Expts 2013-1 to 2013-17 are shown on the EC maps in the Appendix (p. 149).

Table 3. 2013: List of experiments and basic cultivation details

Expt	Location	Grower	Field	Cultivated	Treatment	Depths	Tractor-Machine†
2013-1	Hales, Norfolk	Greenvale AP	Hales Hospital	11 Apr	Destoner depth	6	Case 145 CS170
2013-2	Hales, Norfolk	Greenvale AP	Hales Hospital	11 Apr	Destoner depth	6	NH T6080 CS170
2013-3	Coltishall, Norfolk	LF Papworth Ltd	Sco Daniels	18 Apr	Destoner depth	6	NH T7.200 CS150
2013-4	Coltishall, Norfolk	LF Papworth Ltd	Sco Daniels	18 Apr	Destoner depth	6	NH T7.200 CS150
2013-5	Aythorpe Roding, Essex	Stevenson Bros	Mow	25 Apr	Destoner depth	6	JD 6930 Megastar Gen-2
2013-6	Aythorpe Roding, Essex	Stevenson Bros	Mow	25 Apr	Destoner depth	6	JD 6930 Megastar Gen-2
2013-7	Bishops Lydeard, Somerset	B & B Potatoes	Portman Lane	9 May	Destoner depth	4	Fendt 820 CS150
2013-8	Barrington, Somerset	Walronds Park Ltd	The Oaks	3 May	Destoner depth	4	JD 6150R CS1500
2013-9	Holt, Norfolk	EG Harrison & Co	Holt Road Pyghtle	28 Mar	Destoner depth	3	JD 6930 CS1500
2013-10	Trimingham, Norfolk	EG Harrison & Co	Low-grounds	30 Apr	Bedforming x destoner depth	3	JD 6930 CS1500
2013-11	Marham, Norfolk	Spearhead Marketing Ltd	Below Bomb Dump	15 Apr	Bedforming x destoner depth	3	Fendt 620 CW150
2013-12	Brome Street, Norfolk	Greenvale AP	Park	9 May	Destoner depth	2	NH T6080 CS170
2013-13	Cambridge, Cambridgeshire	Cambridge University Farm	Osier	17 May	Destoner depth x N	2	Fendt 820 CS150
2013-14	Roudham, Norfolk	WO & PO Jolly	Dyball	22 Apr	Destoner depth x N	2	Case CVX150 Reekie 5174
2013-15	Roudham, Norfolk	WO & PO Jolly	14 E/W	26 Mar	Destoner depth x N	2	Case CVX150 Reekie 5174
2013-16	South Pickenham, Norfolk	Spearhead Marketing Ltd	Top of Curlews	2 Apr	Destoner depth x N	2	JD 6150R CS150
2013-17	Knettishall, Suffolk	Spearhead Marketing Ltd	Buchers Stennetts	24 Apr	Destoner depth x N	3	Fendt 620 CW150
2013-18	Ramsey Hollow, Cambridgeshire	Worlick Farm	Taylors Bottom	1 May	Destoner depth x N	2	JD 7530 CS150
2013-19	Tern, Shropshire	M & RG Levin	Moortown	26 Apr	Primary x secondary	2	JD6930 CS150

†JD = John Deere; NH = New Holland; CS = Grimme Combistar; CW = Grimme Combiweb; Megastar = Standen Pearson Megastar.

Table 4. 2013: Seed and soil details

Expt	Variety	Soil texture	Sand (%)	Silt (%)	Clay (%)	OM (%)	Seed size (mm)	Seed spacing (cm)
2013-1	Maris Piper	Sandy loam	66	20	15	2.1	35-50	97 x 36
2013-2	Maris Piper	Sandy clay loam	60	18	22	2.2	35-50	97 x 36
2013-3	Saturna	Sandy silt loam	43	42	15	2.1	45-55	91 x 36
2013-4	Saturna	Clay loam	40	41	19	2.0	45-55	91 x 36
2013-5	Desiree	Clay loam	23	49	28	2.5	30-55	91 x 27
2013-6	Desiree	Clay loam	25	44	32	3.2	30-55	91 x 27
2013-7	Sylvana	Clay	41	20	39	3.6	35-50	91 x 40
2013-8	Electra	Sandy silt loam	35	47	21	2.6	35-45	91 x 25
2013-9	Lady Rosetta	Sandy loam	59	31	11	3.1	35-45	91 x 27
2013-10	Hermes	Sandy loam	60	27	13	1.4	35-45	91 x 27
2013-11	Markies	Sandy clay loam	57	15	28	2.1	35-45	91 x 25
2013-12	Venezia	Sandy clay loam	62	18	20	2.3	35-45	91 x 12
2013-13	Maris Piper	Sandy clay loam	52	26	22	5.0	30-40	91 x 28
2013-14	Brooke	Sandy loam	74	16	10	2.3	30-40	91 x 28
2013-15	Maris Piper	Loamy sand	82	9	9	1.1	35-55	91 x 36
2013-16	Linton	Sandy loam	68	15	17	1.9	30-40	91 x 18
2013-17	Linton	Sandy loam	66	16	18	2.1	35-40	91 x 23
2013-18	Markies	Clay	24	41	35	18.3	35-45	91 x 27
2013-19	Maris Piper	Sandy loam	65	17	18	1.6	40-45	91 x 36

3.2.1. Cultivation depth experiments

Experiments 2013-1 to 2013-6 were all of similar randomised block design with four replicates and six depth treatments but with different randomisation. Experiments 2013-7 and 2013-8 had only four depth treatments but six replicates. Basic details were the same as the experiments conducted in 2012 (**3.1.1**).

Experiment 2013-8 was bed-tilled with a Grimme Shapeformer using a Claas Arion 650 on 2 May at the depth required for the destoning treatments and then destoned and planted on 3 May.

In Expt 2013-9, the plots were *c*. 260-290 m long to allow machine harvesting (Grimme Variatron with picking table) and to assess the effect of destoning depth on bruising. There were six replicates of three destoning depths.

Experiments 2013-10 and 2013-11 involved destoning depth treatments superimposed on three (Expt 2013-10) or two (Expt 2013-11) depths of bedforming. In Expt 2013-10, bedforming was carried out using a newly-developed tool designed by Grimme UK Ltd in collaboration with SOYL. The EC scan field map was converted from soil water content into a depth of bedforming depth to avoid cultivating deeper than the critical depth. Destoning depth treatments (25, 35, 45 cm) were superimposed on beds created to three different depths (40, 50, 60 cm) with three replicates.

Experiment 2013-11 was bedformed on 15 April at two depths (45, 60 cm) using a Standen Pearson Bedformer BX pulled with a John Deere 7280R, then destoned to three depths (25, 35, 45 cm). The plots were c. 300 m long to allow machine harvesting (Grimme GT170S with picking table) and to assess the effect of destoning depth on bruising. There were three replicates of each of the six treatment combinations.

Experiment 2013-12 was bed-formed at the depth required for the destoning treatments (25, 35 cm) using the same experimental bedformer as in Expt 2013-10. The plots were *c.* 400 m long to allow machine harvesting (Grimme Varitron with picking table) and to assess the effect of destoning depth on bruising. There were six replicates of the two treatments.

3.2.2. Nitrogen x cultivation depth experiments

Experiments 2013-13 to 2013-18 consisted of two destoning depths (typically 25 and 35 cm) in all experiments except Expt 2013-17 where there were three depths (25, 35, 50 cm) and two rates of nitrogen (N) treatments (0 and 200 kg N/ha) in factorial designs with six replicates (three in Expt 2013-17).

Experiment 2013-13 was bedtilled and formed using a Grimme single bed tiller towed by a Fendt 820 tractor. The shallow plots were destoned at 35 cm and the deep at 52 cm. Nitrogen on the N200 treatments was applied to the stubble ahead of the bedtiller using ammonium nitrate (34.5 % N). Each plot was 20 m long and six rows wide.

In Expts 2013-14 and 2013-15, the N treatments were applied to bare soil just prior to emergence on using liquid ammonium sulphate (26 % N). Each plot was 20 m long and ten rows wide.

In Expt 2013-16, the N treatments were applied using a Horstine Farmery band applicator mounted on the planter. The urea fertilizer (46 % N) was incorporated into the bed in front of the opening shares. The applicator was turned off for 0 N treatments. Each plot was 20 m long and four rows wide.

In Expt 2013-17, the shallow plots were destoned at 24 cm, the commercial depth at 35 cm and the deep at 52 cm. The N treatments were applied using a Horstine Farmery band applicator mounted on the planter. The urea fertilizer (46 % N) was incorporated into the bed in front of the opening shares. The applicator was turned off for 0 N treatments. Each plot was 20 m long and six rows wide.

In Expt 2013-18, the shallow plots were destoned at 25 cm and the deep at 35 cm. The N treatments were applied using a Horstine Farmery band applicator mounted in front of a Grimme bedtiller towed by a John Deere 7530. The rate of ammonium nitrate fertilizer (34.5 % N) was adjusted to give a rate of 180 kg N/ha for '200 N' plots and incorporated into the bed in front of the opening shares. The applicator was turned off for 0 N treatments. Each plot was 20 m long and six rows wide.

3.2.3. Machine x cultivation depth experiments

Experiment 2013-19 formed part of the work in Potato Council Project R444 managed by Martyn Silgram and Di Williams of ADAS. The plough treatment was ploughed to 20 cm depth using a 5-furrow reversible plough and a John Deere 6930. The non-inversion primary treatment was done using a Simba DTX with tines operating at 40 cm depth and the discs at 15 cm depth followed by the roller, which was towed by Claas 650 tractor. The secondary cultivations were conducted on 26 April. The shallow plots were destoned at 25 cm and the deep at 35 cm. The Tillerstar (two-bed version, 2013 model) was operated at 30 cm depth and towed with a Massey Ferguson 8670 tractor.

3.2.4. General methodology

The general methodology used in 2013 was largely the same as in 2012 (see **3.1.4**). The soil water content in bedformed soil in Expts 2013-1 to 2013-8 was measured immediately prior to destoning. In Expts 2013-1 to 2013-7, plant emergence was recorded every 2-3 days. Ground covers were taken weekly on plots in Expts 2013-1, 2013-2 and 2013-18. All experiments were irrigated according to the Cambridge University Farm Potato Irrigation Model. Estimates of the quantity of soil removed into the furrow during destoning, soil bulk density, ridge bulk density, resistance, ped size distribution and nitrogen determination were all measured as in 2012 (see **3.1.4**).

In Expts 2013-9, 2013-11, 2013-12, 2013-15 and 2013-17, the plots were commercially-harvested using Grimme Varitron self-propelled or Grimme GT trailed harvesters. Crates were positioned on the picking table to allow 100-200 tubers to be randomly selected along the length of the plots. In Expts 2013-9 and 2013-12, all clods and stones were collected from the picking table into separate crates for weighing to determine the stone/clod tare.

3.3. 2014

In 2014, there were 17 experiments conducted on sites in Cambridgeshire, Essex, Norfolk, Staffordshire, Suffolk and Sussex in the UK and County Meath in Ireland investigating the effect of bed depth and sieving aggressiveness on soil parameters, crop yield and quality and harvesting damage (Table 5). During September 2013 to March 2014, most of these fields were surveyed using EC scanning. Seven fields had existing EC maps conducted in the last 4 years. The resulting EC images were used to select suitable fields where there was significant variation in apparent water content. To cover the contingency of being able to visit sites when they were being planted or other reasons, more fields were selected than required. Five fields scheduled for experiments were abandoned owing to a clash of timing or duplication.

The list and basic cultivation details of the experiments conducted in 2014 are given in Table 5 and seed and soil details in Table 6. The locations of Expts 2014-1 to 2014-16 are shown on the EC maps in the Appendix (p. 149).

Table 5. 2014: List of experiments and basic cultivation details

Expt	Location	Grower	Field	Cultivated	Treatment	Depths	Tractor-Machine†
2014-1	Hales, Norfolk	Greenvale AP	The Cliff	1 Apr	Destoner depth	6	NH T6080 CS170
2014-2	Hales, Norfolk	Greenvale AP	The Cliff	4 Apr	Destoner depth	6	Case 145 CS170
2014-3	Aythorpe Roding, Essex	Stevenson Bros	Langlands	4 Apr	Destoner depth	6	JD 6930 Megastar Gen-2
2014-4	Tuttington, Norfolk	LF Papworth Ltd	Tutt Pad	28 Apr	Bed x destoner depth	Variable	NH T7.200 CS150
2014-5	Tillington, Sussex	Basil Baird (Fareham) Ltd	Ball	1 Apr	Machine x destoner depth	3	NH T7.170 CS150/ CW150
2014-6	Brampton, Norfolk	B & C Farming	Oxnead 6E	31 Mar	Machine x destoner depth	3	See text
2014-7	Booton, Norfolk	B & C Farming	Booton 33	9 Apr	Machine x destoner depth	3	See text
2014-8	Prickwillow, Cambridgeshire	Barway Farms	Kings 1	8 Apr	Machine x depth	2	JD 6150R Megastar
2014-9	Cambridge, Cambridgeshire	NIAB-CUF	Coprolite	25/28 Mar	Plough, non-plough	-	JD 6150R Rumptstad
2014-10	Thorpe Constantine, Staffordshire	WB Daw & Sons	Thorpe 30	22 Apr	Destoner depth x N	3	JD 6150R CS150
2014-11	Thorpe Constantine, Staffordshire	WB Daw & Sons	Thorpe 41	29 Apr	Destoner depth x N	3	JD 6150R CS150
2014-12	Great Cressingham, Norfolk	Spearhead Marketing Ltd	Caudle	30 Apr	Destoner depth x N	3	JD 6150R CS150
2014-13	Navan, Ireland	Largo Foods	Danes-town	7 May	Destoner depth x N	3	JD 6190R CS1500
2014-14	Great Cressinham, Norfolk	Spearhead Marketing Ltd	Caudle	2 May	Profile x tilth x pressure	-	JD 6150R CS150
2014-15	Hunworth, Norfolk	EG Harrison & Co	Mount 40 Ac	20 Mar	Destoner depth	3	MF 7480 CS150
2014-16	Briston, Norfolk	EG Harrison & Co	Bush Breck	25 Mar	Destoner depth	3	MF 7480 CS150
2014-17	Risby, Suffolk	Spearhead Marketing Ltd	Cage Left	17 Apr	Destoner depth	3	

†JD = John Deere; MF = Massey Ferguson; NH = New Holland; CS = Grimme Combistar; CW = Grimme Combiweb; Megastar = Standen Pearson Megastar; Rumptstad = Rumptstad Rototiller.

Table 6. 2014: Seed and soil details

Expt	Variety	Soil texture	Sand (%)	Silt (%)	Clay (%)	OM (%)	Seed size (mm)	Seed spacing (cm)
2014-1	Maris Piper	Sandy loam	78	12	10	1.8	35-50	97 x 36
2014-2	Maris Piper	Sandy clay loam	55	19	26	1.8	35-50	97 x 36
2014-3	King Edward	Clay loam	26	46	29	2.3	35-55	91 x 37
2014-4	Galante	Sandy silt loam	44	38	18	2.0	25-35	91 x 13
2014-5	Piccolo Star	Sandy loam	61	22	18	1.8	35-45	91 x 15
2014-6	Maris Piper	Clay loam	43	38	19	2.1	30-40	91 x 28
2014-7	Russet Burbank	Sandy loam	73	14	12	1.5	30-40	91 x 29
2014-8	Maris Piper	Peaty clay loam	27	40	33	21.3	45-55	91 x 42
2014-9	Maris Piper	Sandy loam†	60	19	21	3.8	30-40	76 x 30
		Sandy clay loam‡	36	31	33	4.6	30-40	76 x 30
2014-10	VR808	Clay loam	43	29	28	3.4	50-60	91 x 35
2014-11	VR808	Clay loam	32	35	33	3.2	50-60	91 x 35
2014-12	Saturna	Sandy clay loam	68	15	17	1.9	35-45	91 x 29
2014-13	Endeavour	Clay	37	25	38	4.1	35-40	91 x 29
2014-14	Saturna	Sandy clay loam	69	15	16	1.8	35-45	91 x 29
2014-15	Hermes	Sandy loam	53	31	16	1.8	30-60	91 x 21
2014-16	Innovator	Sandy loam	61	24	15	1.5	35-45	91 x 28
2014-17	Markies	Loamy sand	83	9	8	1.2	30-40	91 x 25

†Light area; ‡ Heavy area

3.3.1. Cultivation depth experiments

Experiments 2014-1 to 2014-3 were of similar randomised block design with four replicates and six depth treatments but with different randomisation. Experiment 2014-4 had two replicate strips each of continuously-variable and fixed depth bed-forming. The actual depths for each experiment were determined during a calibration procedure in the surrounding commercial field. In Expts 2014-1 to 2014-3, the target was to have three depths shallower than standard commercial depth used in the field one at the commercial depth and two depths deeper than standard. Basic details were the same as the experiments conducted in 2012 (**3.1.1**).

Experiment 2014-4 was located on a predominantly sandy silt loam soil but with areas of slightly higher (19-20 %) clay content. Bedforming was carried out on 28 April using a newly-developed tool designed by Grimme UK Ltd in collaboration with SOYL. The EC scan field map (measurements taken March 2014) was converted from soil water content into a bedforming depth to avoid cultivating deeper than the critical depth. The bedforming depths ranged from 35 to 45 cm, with the shallowest depth corresponding with the wettest soil and the deepest with the driest. The Grimme bedformer was towed by a Claas Arion 630 tractor and a total of 24 beds of variable-depth bedforming was done. There was a 12-bed strip of the standard commercial depth (54 cm) in the middle of two 12-bed variable-depth (35-45 cm) strips and another 12 beds of standard depth beds were pulled up either side of each variable-depth strip. The depth control on the destoner was set to automatic which resulted in a finished bed depth of 36 cm. The variable-depth bedforming strips were destoned using automatic so that the height of the bed determined the maximum depth of destoning. In the shallowest beds, destoning depth was 27.7 cm and in the deepest 33.7 cm. A final harvest was consisted of five digs of 1.5 m of three-row bed in each of the three 12-bed commercial-depth strips (total 15 digs). The positions of the digs in the variable-depth areas were determined by using the GPS coordinates from the EC scanner so that a single dig was conducted in three different areas where the bedforming resulted in bed depths of 35, 37.5, 40.0, 42.5 and 45 cm (total 15 digs).

3.3.2. Machine x cultivation depth experiments

Experiments 2014-5 to 2014-9 used combinations of different cultivation machinery to produce beds for planting, mostly in combination with depth of cultivation.

Experiment 2014-5 was a randomised design of three destoning machines and three depths of cultivation with three replicates. It was destoned using three machines according to the treatment: a Grimme CS150 with the stars fully closed, another CS150 with the stars wide open and a CW150 web machine with a 28 mm rear web. All beds were bedtilled shallowly (25 cm) using a Grimme bedtiller prior to destoning. A hand-dug sample for yield was harvested on 31 July. The plots were 200 m long to allow machine harvesting (Grimme Varitron 220 self-propelled with picking table). On 31 July, samples of > 100 random tubers from each plot were taken from the beginning of the cart elevator of the harvester to measure bruising. The depth of the harvester share was fixed at a relative value of 70 % (standard commercial depth). At the same time as selecting the tubers for bruising, all the stone and clod produced when harvesting one bed of each plot was collected from the picking table. The stone and clod was then weighed. Following storage at 8 °C, the tubers were assessed on 10 November for incidence of bruising after peeling tubers in a rumble peeler.

Experiment 2014-6 was a replicated experiment split-plot, with main plots being laid out for two types of destoning machine and with sub-plots allocated to three depths of destoning. Sub-plots were 60 m in length and 12 rows wide and there were six replicates of each treatment. Two different machines were used to create the beds for planting. Traditional destoning following primary cultivation with a Sumo Trio and bedforming was carried out using a Grimme CS1500 towed by a John Deere 6170R tractor on 31 March. The second method of forming beds was using a George Moate Ltd 2-bed Tillerstar directly on to soil which had been shallow cultivated with a Sumo Trio. The bladed rotor of the Tillerstar rotates in opposite direction to the working direction so that soil passes over the top of the rotor and out of the back of the housing. Soil lands on four flexible-finger star rollers (the same as used on conventional stone and clod separators) positioned close behind. These rollers sieve the loose soil and convey any stone or clod forwards in to the void behind the rotor. They are then covered by soil falling between the rollers as the machine moves forward. The machine was towed by a 325 horsepower John Deere 8335R tractor. Beds of 25, 30 and 35 cm depth were made by each machine. Following destoning/bedtilling, the experimental area was planted on 31 March using 30-40 mm Maris Piper seed at a within-row spacing of 28 cm in 91 cm rows. A hand-dug final harvest was conducted on 22 September. On 2 October, samples of > 50 random tubers from each plot were taken from the beginning of the cart elevator of a Grimme Varitron 220 self-propelled harvester to measure bruising. The depth of the harvester share was adjusted to match the destoned bed depth, so that the 25 cm treatments were harvested with the Varitron depth gauge set at 68 %, 30 cm treatments at 71 % and 35 cm treatments at 76 % (standard commercial depth). At the same time as selecting the tubers for bruising, two operators on the picking table removed all the stone and clod produced when harvesting one bed of each plot. The stone and clod was then weighed. Following storage at 8 °C, the tubers were assessed on 1 November for incidence of bruising after peeling tubers in a rumble peeler.

In Expt 2014-7, the experimental design was the same as Expt 2014-6. Sub-plots were 30 m long and 12 rows wide and there were six replicates of each treatment.

Experiment 2014-8 was arranged in a factorial design of four treatments: bedtill shallow or deep in combination with destoning or not destoning, with four replicate blocks. Prior to bedtilling, the field was subsoiled and bedformed in the autumn and then the beds were pulled down with a chisel plough cultivator 1-2 days prior to bedtilling. The bedtilling treatments were carried out on 8 April using a Basilier bedtiller towed by a 345 horsepower John Deere 8345. The shallow bedtilling treatment was carried out at 23 % on the tractor's hydraulic link arms and the deep at 13 %. These resulted in tilled depths of 24 and 29 cm, respectively. Plots were 155 m long and six rows wide.

Experiment 2014-9 comprised two unreplicated blocks of soil in different parts of the field, which were then subdivided into plough and non-plough treatments. The 'light' soil type was located on a sandy clay loam soil and the 'heavy' soil type was located on a clay loam soil. The ploughed treatments were ploughed on 17 March, whilst the unploughed areas were cultivated with a combination disc/tine cultivator on 20 March. Following primary cultivation, the area was roto-ridged using a Rumptstad rototiller on 20 March in the light area and 26 March in the heavy. Planting was carried out by hand on 16 April in plots 10 m long and 10 rows wide. A hand-dug final harvest was conducted with three replicate areas in each treatment.

3.3.3. Nitrogen x cultivation depth experiments

Experiments 2014-10 to 2014-13 included all combinations of three destoning depths (typically 25, 30 and 35 cm) and two rates of nitrogen (N) treatments (0 and 200 kg N/ha) arranged in randomized designs with four replicates.

In all N experiments, the N treatments were applied using a Horstine Farmery band applicator mounted on the planter. The rate of ammonium nitrate (34.5 % N) or urea (46 %; Expt 2014-12) fertilizer was adjusted to give 200 kg N/ha for 200 N plots and incorporated into the bed in front of the opening shares. The applicator was turned off for 0 N treatments. Each plot was 15 m long and six rows wide.

3.3.4. Planter profile experiments

Experiment 2014-14 was set up to examine the effect of seedbed tilth, ridge profile and ridge compression on yield and greening. It was arranged as a factorial design with two tilths (cloddy and fine), two ridge profiles (trapezoidal and a semi-bed profile with a very shallow central furrow) and two planter forming hood pressures (low (0 %) and high (the maximum pressure that allowed soil to flow through the planter covering shares and planter forming hood)), with three replicate blocks. The different tilth treatments were achieved by operating the destoner at 4 km/h with the stars wide open (coarse) and at 2 km/h with the stars fully closed (fine). To achieve the different ridge profiles, the central ridging body at the rear of the planter was removed in the bed treatment and left in place in the trapezoidal treatment to produce a pair of ridges. For all plots at 0 % hood pressure, a consistent planting depth was achieved but when the hood pressure was increased to maximum in fine tilth, planting was 2-3 cm deeper than in coarse-tilth soils. Therefore, to achieve the same planting depth, in fine-tilth soil the maximum hood pressure was 60 %, whereas it was 90 % pressure in coarse tilth. Each plot was 20 m long and six rows wide.

3.3.5. Harvesting x cultivation depth experiments

Five experiments were set up with destoning depth as a treatment where the plots were sufficiently long to harvest with a commercial harvester and select tubers off either the cart elevator on the harvester or from the receiving trailer to assess the effects of harvesting damage. Sites we selected either for their high stone content (Expts 2014-15 to 2014-17) or if different types of destoning machinery were used (Expts 2014-5 and 2014-6, described previously).

Experiments 2014-15 to 2014-17 were carried out on soils with moderate (10-25 %) or high (20-35 %) stone content to test the effects of destoning depth on bruising damage to tubers. In each randomised experiment, there were three depths of destoning (commercial depth and two shallower depths) and eight replicates. The plots were two beds wide (3.65 m) and either the full length of the field or at least 100 m long to allow commercial harvesting to proceed at normal rates whilst sampling of tubers took place. At least 100 tubers were bagged from each plot and samples were stored at 8 °C until assessment. They were peeled in a rumble peeler and the number of tubers with one or more blackspot bruises was counted along with the total number of tubers in each sample.

In Expt 2014-15, the plots were 200 m long to allow machine harvesting (Grimme Varitron 220 self-propelled with picking table). On 10 September, samples of > 50 random tubers from each plot were taken from the beginning of the cart elevator of the harvester to measure bruising. The depth of the harvester share was adjusted to match the destoned bed depth, so that the 25 cm treatments were harvested with the Varitron depth gauge set at 62 %, 30 cm treatments at 65 % and 35 cm treatments at 69 % (standard commercial depth). These relative depths were selected by raising the harvester share progressively until tubers were sliced and then dropping down 2 % to avoid slicing tubers because of inadequate depth. At the same time as selecting the tubers for bruising, all the stone and clod produced when harvesting was collected from one bed of each plot. The stone and clod was then weighed. No yield digs were taken. The tubers were assessed for bruising on 21-24 November.

In Expt 2014-16, the plots were 130 m long to allow machine harvesting (Grimme Varitron 220 self-propelled with picking table). On 29 September, samples of > 50 random tubers from each plot were taken from the beginning of the cart elevator of the harvester to measure bruising. In one bed of the plot, the harvester share was set at the commercial depth (69 %) irrespective of the depth of destoning whilst in another bed, the depth of the harvester share was adjusted to match the destoned bed depth (as in Expt 15), so that the 25 cm treatments were harvested with the Varitron depth gauge set at 62 %, 30 cm treatments at 65 % and 35 cm treatments at 69 % (standard commercial depth). At the same time as selecting the tubers for bruising, all the stone and clod produced when harvesting was collected from one bed of each plot. The stone and clod was then weighed. The tubers were assessed for bruising on 1 December. No yield digs were taken.

In Expt 2014-17, the plots were harvested on 30 September using a Grimme GT170 trailed harvester and as in Expts 2014-15 and 2014-16, the harvester share depth was varied according to the depth of destoning. The relative depths were 65 % for 25 cm treatments, 75 % for 30 cm and 85 % for 35 cm. Tubers samples for bruising assessment were selected randomly along the full length of the plot (100 m) from the trailer being towed alongside the harvester. The samples were assessed for bruising on 20 November. No yield digs were taken.

3.3.6. General methodology

The general methodology used in 2014 was largely the same as in 2012 and 2013 (see **3.1.4**). The soil water content in bedformed soil in Expts 2014-1 to 2014-7 was measured immediately prior to destoning. In Expts 2014-1 to 2014-3 and 2014-6 and 2014-7, plant emergence was recorded every 2-3 days. Estimates of the quantity of soil removed into the furrow during destoning, soil bulk density, ridge bulk density, resistance, ped size distribution and nitrogen determination were all measured as in 2012 (see **3.1.4**).

The soil water content in Expts 2014-1 to 2014-13 was measured immediately prior to destoning using a Delta-T Devices Theta Probe in soil which had been bedformed just prior to measurement. Measurements were taken in every plot of the experiment by excavating a pit to 40-60 cm depth and measuring the mean water content in three walls of the pit at 5 cm depth intervals.

In Expts 2014-1, 2014-2, 2014-3, 2014-6, 2014-7, 2014-9, 2014-12 and 2014-14, plant emergence was recorded every 2-3 days in each plot by counting the number of plants emerged in two harvest rows. Emergence was estimated from observations made by collaborators in other experiments. Planting depth was estimated by measuring the length of a below-ground stem from five random plants in each plot between full plant emergence and final harvest. A final harvest of 3 m from a single row (1.5 m of bed in Expt 2014-5) was taken in July-October. All experiments were irrigated and all except Expt 2014-5, 2014-8, 2014-10 and 2014-11used the Cambridge University Farm Potato Irrigation Scheduling Model.

In Expts 2014-1 to 2014-3, the dry bulk density of the soil was measured. Soil resistance readings were taken using an Eijkelkamp Penetrograph penetrometer (1 cm^2 60° cone tip) in the centre of the ridge to a depth of 50 cm immediately following planting. Three replicate readings of resistance were taken in each plot of the detailed cultivation depth experiments (Expts 2014-1 to 2014-3). Ridge bulk density and ped size distribution was measured at planting and final harvest in the detailed depth experiments.

At each of the four sites in Expts 2014-10 to 2014-13, soil mineral nitrogen (SMN) was measured on two occasions: at about the time of crop emergence and when the crops were harvested by hand in September or October. Foliage from each plot at the final harvest was weighed, sub-sampled to *c*. 1 kg and dried. Dried haulm and tuber samples were analysed for total N content at Natural Resource Management Ltd.

4. RESULTS

4.1. 2012

4.1.1. Actual depths of destoning

The actual depth of the destoned bed prior to planting compared with intended varied across experiments in relations to soil type. Where soils were sandy loam in texture, it was easy to achieve depths close to 50 cm, whereas on sandy clay loam it was difficult to achieve beds deeper than 45 cm even with the deepest setting as soil was wet and produced clods which were transported to the cross conveyor and into the adjacent wheeling. Therefore, there were some experiments (e.g. Expts 2012-2 and 2012-6) where working deeper resulted in considerably less soil ending up in the finished bed than with the standard commercial depth. This is shown in Table 7. Throughout the rest of this part of the report, the destoner depths will be referred to as depths 1…6 and by reference to Table 7, the true depth of bed can be determined for experiments conducted in 2012.

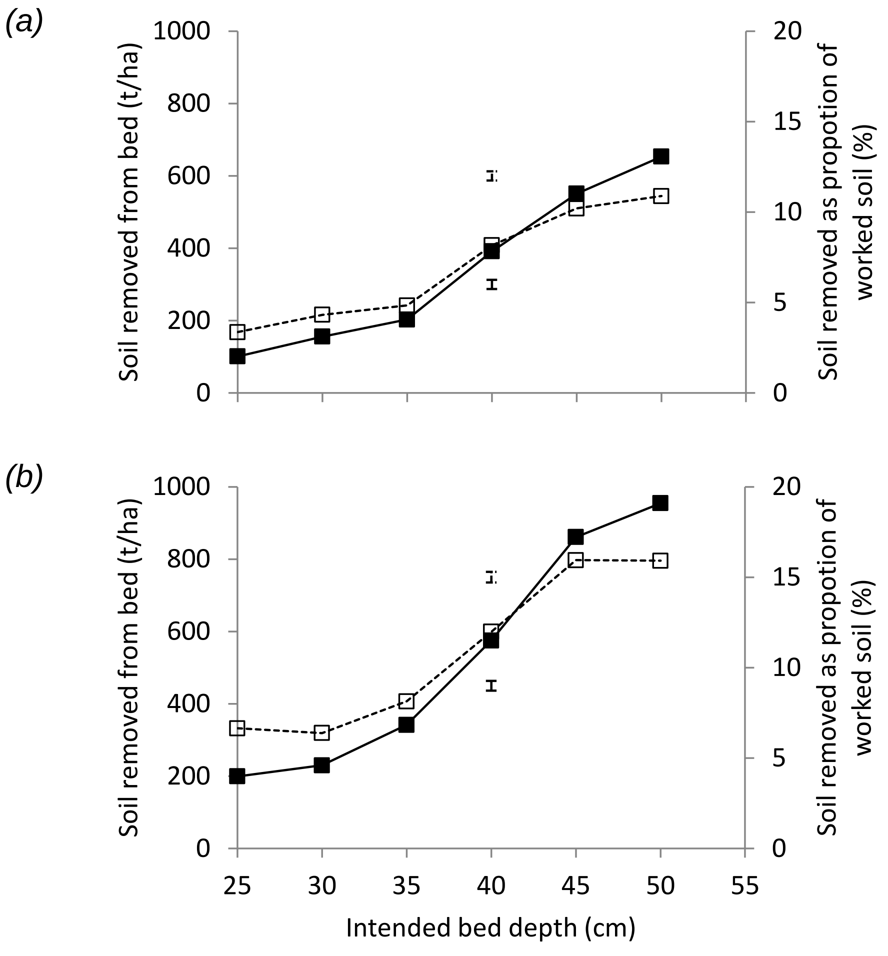
Table 7. 2012: Intended and actual achieved depth (cm) of destoning in Expts 2012-1 to 2012-7

		Destoning depth					
Expt	Intended (I) vs Actual (A)	1 Shallowest	2	3 Commercial	4	5	6 Deepest
2012-1	I	25	30	35	40	45	50
	A	25	30	36	41	46	51
2012-2	I	25	30	35	40	45	50
	A	24	28	34	36	36	32
2012-3	I	25	30	35	40	45	50
	A	22	29	33	38	43	48
2012-4	I	25	30	35	40	45	50
	A	23	29	34	37	41	46
2012-5	I	25	30	35	40	45	50
	A	22	25	30	35	40	45
2012-6	I	25	30	35	40	45	50
	A	20	24	30	33	26	24
2012-7	I	18	22	25	30	35	40
	A	18	20	22	25	30	36

4.1.2. Soil removed from bed during destoning

In Expts 2012-5 and 2012-6, the weight of soil removed from the bed and deposited into the adjacent wheeling was measured. In Expt 2012-5, as depth of destoning increased, the weight of soil removed increased only very slightly until the share reached a depth capable of producing a bed depth of 35 cm (Figure 1*a*). At that point there was an increase in the amount of soil removed as the destoner share went deeper. At the commercial depth (between 35 and 40 cm), *c*. 600 t/ha of soil was removed from the bed into the furrow. In the higher clay content area of the field (Expt 2012-6), more soil was removed at the equivalent share depth to Expt 2012-5 but there was still a sharp increase in the amount of soil removed as the share worked the bed deeper than 35 cm (Figure 1*b*). At the deepest share depth, *c*. 1000 t/ha (16 %) of soil was removed into the furrow.

Figure 1. 2012: Quantity of soil removed from bed (solid line and symbols) and proportion of soil transferred to furrow (dashed line and open symbols) during destoning in *(a)* Expt 2012-5 and *(b)* Expt 2012-6. Bars indicate S.E. based on 15 D.F.



4.1.3. Rate of work and fuel consumption

The spot forward speeds of the different destoner depth treatments are shown in Table 8 and the spot rate of work in Table 9. There were considerable differences in speed and rate of work between experiments and light and heavy sites within fields.

The sites with higher clay content were generally cultivated slower than where the clay content was lower but Expt 2012-7 had the highest clay content and when producing destoned beds 30 cm deep the rate was 1.59 km/h whereas in Expts 2012-2 and 2012-4 the rate of destoning was 0.85-0.93 km/h (Table 8). Experiment 2012-7 was destoned using a Standen Pearson Megastar which has a shorter separation area than the Grimme Combistar machines used in other experiments. Within fields, there was considerable variation, e.g. average spot speed and rate of work in Expt 2012-2 (sandy clay loam) was only 46 % of Expt 2012-1 (sandy loam) and in Expt 2012-6 (29 % clay content) was only 66 % of Expt 2012-5 (24 % clay; Table 8 and Table 9).

Table 8. 2012: Spot forward speeds (km/h) of destoner treatments in Expts 2012-1 to 2012-7

	Depth of destoning					
Expt	1 Shallowest	2	3 Commercial†	4	5	6 Deepest
2012-1	1.93	1.74	1.68	1.31	1.28	0.99
2012-2	1.03	0.85	0.84	0.59	0.54	0.28
2012-3	4.44	2.85	2.50	2.48	2.30	1.79
2012-4	4.24	2.53	2.31	2.25	2.11	1.35
2012-5	1.89	1.65	1.46	1.28	1.10	1.03
2012-6	1.25	1.04	0.93	0.89	0.77	0.68
2012-7	3.63	3.53	3.04	2.15	1.59	1.16

†22 cm in Expt 2012-7, 34-36 cm in all other experiments

Table 9. 2012: Spot rates of work (ha/h) of destoner treatments in Expts 2012-1 to 2012-7

	Depth of destoning					
Expt	1 Shallowest	2	3 Commercial†	4	5	6 Deepest
2012-1	0.35	0.32	0.31	0.24	0.23	0.18
2012-2	0.19	0.16	0.15	0.11	0.10	0.05
2012-3	0.81	0.52	0.46	0.45	0.42	0.33
2012-4	0.78	0.46	0.42	0.41	0.39	0.25
2012-5	0.35	0.30	0.27	0.23	0.20	0.19
2012-6	0.23	0.19	0.17	0.16	0.14	0.12
2012-7	0.66	0.65	0.56	0.39	0.29	0.21

†22 cm in Expt 2012-7, 34-36 cm in all other experiments

Fuel consumption of different treatments is shown in Table 10. Working soil very deeply to create a seedbed in cloddy conditions on heavy soils (e.g. Expts 2012-2 and 2012-6) resulted in a substantial increase in fuel consumption, however the deepest beds at the heaviest site (Expt 2012-7) consumed 40 l/ha of diesel, whereas the equivalent depth of bed in Expts 2012-2, 2012-5 and 2012-6 consumed appreciably more (57-90 l/ha, Table 10). When comparing the standard depth (34-36 cm) across all sites, fuel cost varied from 29 to 107 l/ha. Reducing the depth of destoning by 10 cm to 25 cm rather than 35 cm reduced fuel consumption by *c*. 16 l/ha (£12/ha based on £0.766/l) when averaged across all sites.

Table 10. 2012: Fuel consumption (l/ha) of destoner treatments in Expts 2012-1 to 2012-7.

	Depth of destoning					
	1	2	3	4	5	6
Expt	Shallowest		Commercial†			Deepest
2012-1	26.0	29.5	34.1	44.3	51.2	65.5
2012-2	45.6	55.1	64.5	83.9	96.6	182.6
2012-3	20.3	26.8	28.6	30.7	35.2	44.4
2012-4	21.9	31.0	32.5	33.8	38.9	56.0
2012-5	41.4	51.6	57.7	67.7	83.2	90.6
2012-6	63.9	78.8	90.2	107.4	116.0	139.6
2012-7	12.9	14.9	19.7	27.7	34.1	40.1

†22 cm in Expt 2012-7, 34-36 cm in all other experiments

4.1.4. Soil measurements

4.1.4.1. Soil water content at cultivation

Figure 2 shows the soil water content throughout the profile in deep beds immediately prior to destoning Expts 2012-1 to 2012-7. Using soil texture, organic matter and bulk density data collected during soil sampling post-planting, the lower Plastic Limit (PL, the minimum water content that a soil begins to deform plastically) was calculated from Equation 13 in Keller & Dexter (2012) and checked by performing the Atterberg Limit (rolling a thread to 3 mm) test. The PL was plotted on the graphs of soil water content measured at planting (Figure 2 to Figure 4). In Expt 2012-1, the soil water content in the bed prior to destoning varied little and was 5-6 % drier than the PL (Figure 2*a*). In the heavy area of the same field (Expt 2012-2), the soil water content exceeded the PL below 35 cm and therefore destoning deeper than this would probably have resulted in plastic deformation i.e. compaction at the share depth (Figure 2*a*). When relating the height from the top of a bedformed bed, the true critical depth with respect to a flat soil surface would have been 24 cm. In Expts 2012-3 and 2012-4, the soil water content increased with depth and the PL was only exceeded in Expt 2012-4 at depths >45 cm (Figure 2*b*). In Expts 2012-5 and 2012-6, the soil water content again increased with depth and the PL was exceeded in Expt 2012-5 and Expt

2012-6 at depths > 45 cm (Figure 2*c*). In Expt 2012-7, the soil was much wetter than at other sites and the PL was exceeded closer to the surface (*c*. 30 cm, Figure 3). In all instances where cultivation was conducted in soil wetter than the PL, compaction would be expected. In Expt 2012-8, the soil water content increased with depth and was numerically, but not significantly, greater in the subsoiled plots below 20 cm than in the non-subsoiled plots (Figure 4). The soil at all depths was close to the PL but did not exceed it. In Expt 2012-10, the mean soil water content at 15 and 25 cm was 17.7 ± 0.46 % and 18.6 ± 0.46 %, respectively. In Expt 2012-11, the mean soil water content at 15 and 25 cm was 20.9 ± 0.70 % and 21.2 ± 0.77 %, respectively. All soil cultivated in Expt 2012-11 was below the PL.

Figure 2. 2012: Profile of soil water content (thin line) and lower plastic limit (thick line) in deep beds immediately prior to destoning. *(a)* Expts 2012-1 and 2012-2; *(b)* Expts 2012-3 and 2012-4; *(c)* Expts 2012-5 and 2012-6. Experiment in light soil, ■; Experiment in heavier soil, □. S.E. bars based on 15 D.F.

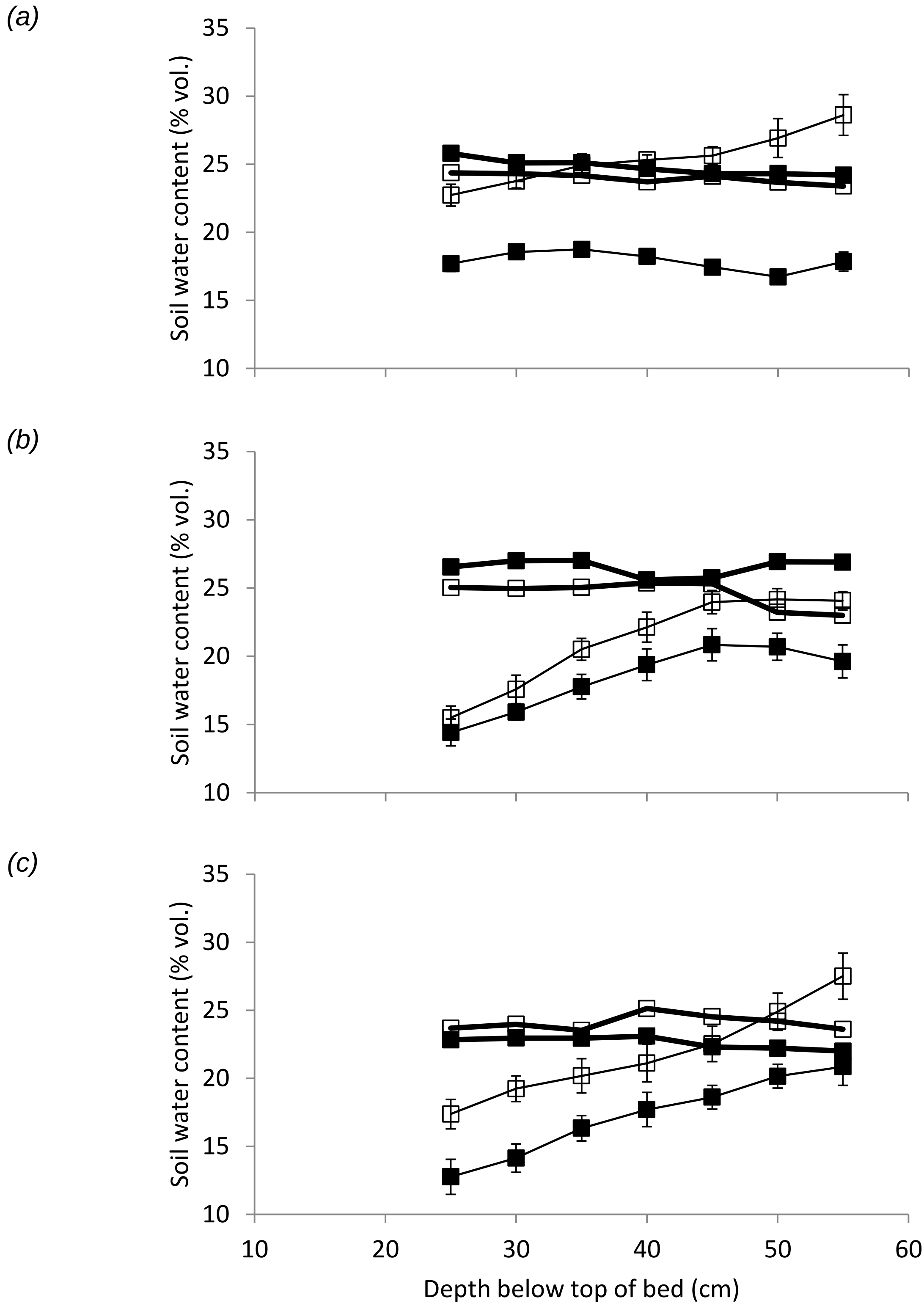


Figure 3. **2012: Profile of soil water content (thin line) and lower plastic limit (thick line) in deep beds immediately prior to destoning in Expt 2012-7. S.E. bars based on 15 D.F.**

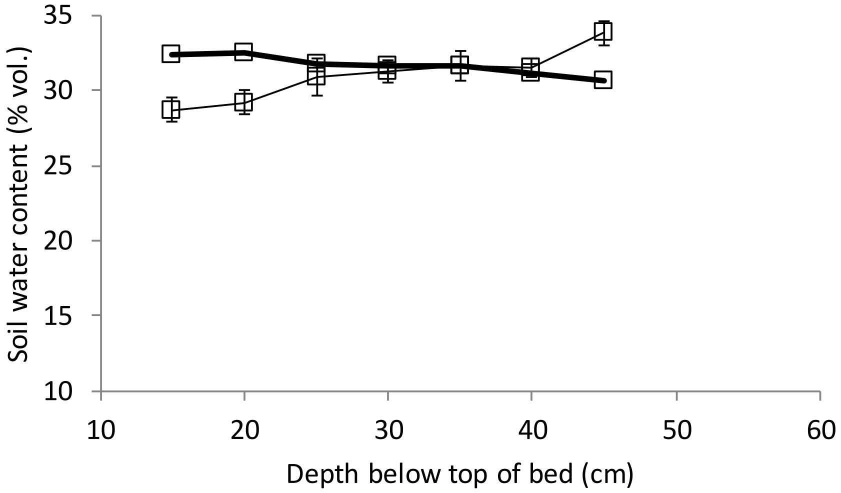
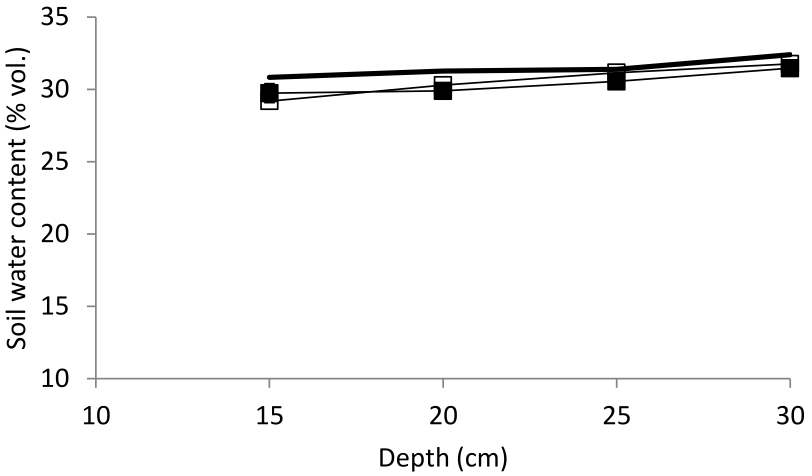


Figure 4. **2012: Profile of soil water content (thin lines) and lower plastic limit (thick line) prior to rototilling in Expt 2012-8. Non-subsoiled, ■; subsoiled, □. S.E. bars based on 15 D.F.**



4.1.4.2. Bulk density

Bulk density measured during July-September was generally reduced with increasing depth of destoning, with the exception of Expts 2012-2 and 2012-6 where destoning substantially deeper than the commercial standard resulted in higher bulk densities at the deepest depths. Unlike 2011 when soils were very dry at depth, there was some evidence in 2012 that deep cultivation resulted in a significant degree of compaction caused by plastic shearing of soil at the destoner share-soil interface.

In the sandy soils of Expt 2012-1, there was no significant effect of destoning depth on mid-season bulk density at any depth (Figure 5*a*). On the heavier site in the same field (Expt 2012-2), increasing the destoning depth reduced bulk density in the uppermost 35 cm of the ridge but had no effect in deeper horizons (Figure 5*b*). In the sandy soil of Expt 2012-3, as in Expt 2012-1, there was no significant effect of destoning depth on bulk density at any depth (Figure 6*a*). In Expt 2012-4, destoning greater than 40 cm deep reduced the bulk density significantly between 30 and 45 cm below the top of the ridge compared with shallower destoning depths. In Expt 2012-5, destoning >40 cm deep generally reduced bulk density between 25 and 40 cm compared with very shallow destoning (Figure 7*a*). In Expt 2012-6, there was no effect of destoning depth on bulk density in any of the horizons measured (Figure 7*b*). In Expt 2012-7, in the top 30 cm of the ridge, bulk density decreased with increasing destoning depth but there was no effect of cultivation depth in horizons deeper than 30 cm (Figure 8).

Figure 5. 2012: Effect of destoning depth on bulk density in *(a)* Expt 2012-1: depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. and *(b)* Expt 2012-2: depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. S.E. bars based on 15 D.F.

(a)

(b)

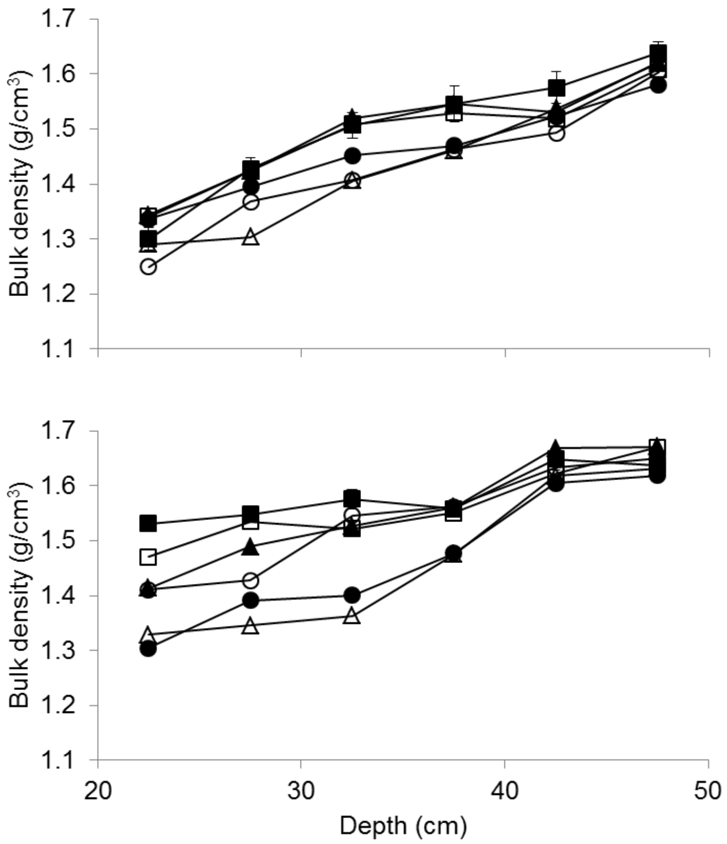


Figure 6. 2012: Effect of destoning depth on bulk density in *(a)* Expt 2012-3 and *(b)* Expt 2012-4. Depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. S.E. bars based on 15 D.F.

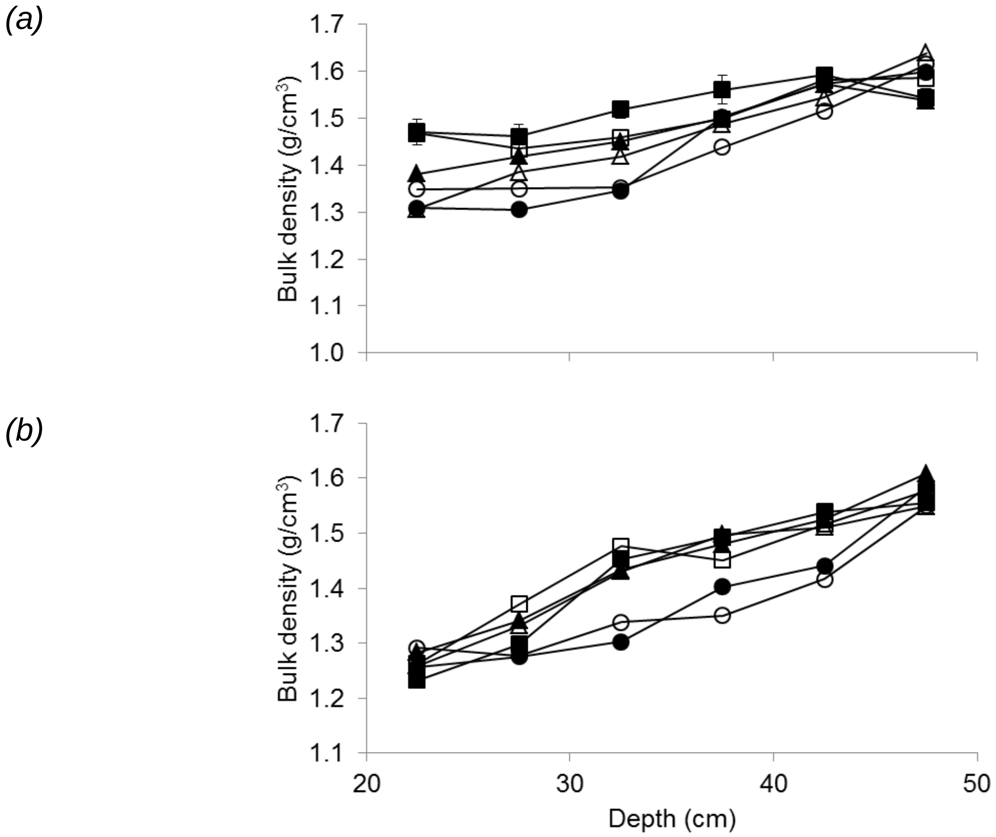


Figure 7. 2012: Effect of destoning depth on bulk density in *(a)* Expt 2012-5: depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○ and *(b)* Expt 2012-6: depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. S.E. based on 15 D.F.

(a)

(b)

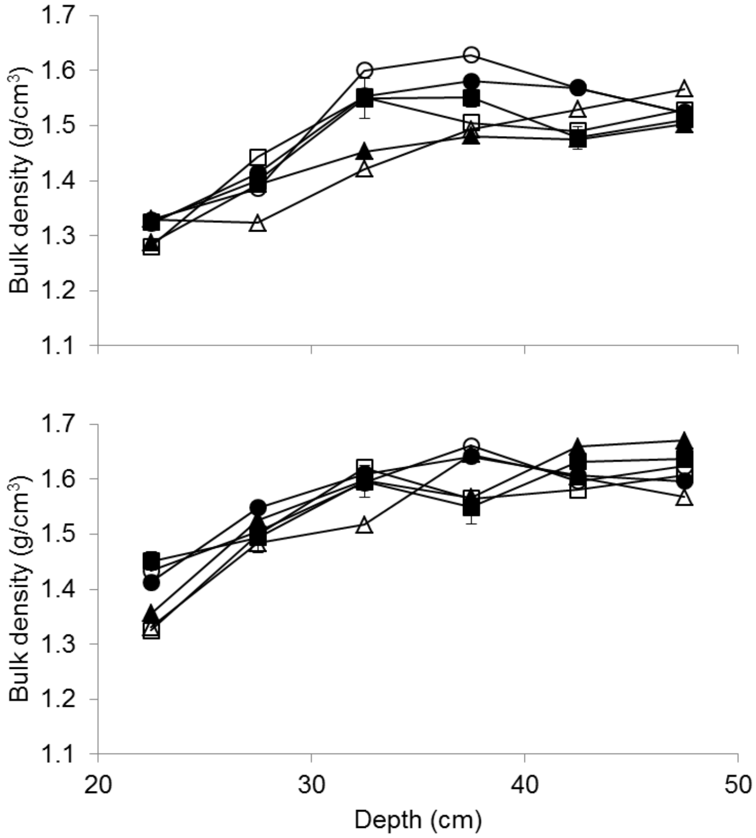
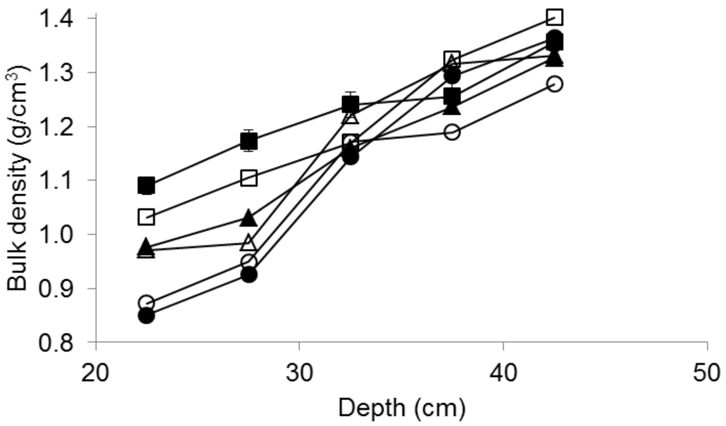


Figure 8. 2012: Effect of destoning depth on bulk density in Expt 2012-7. Depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. S.E. based on 15 D.F.



4.1.4.3. Ridge bulk density

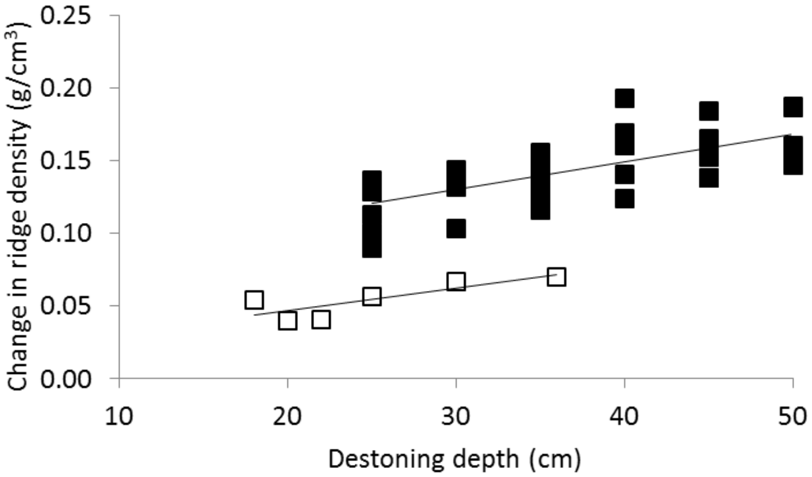
Ridge bulk density at final harvest was not affected by destoning depth in Expts 2012-1, 2012-2, 2012-3 or 2012-4 (Table 11). In Expts 2012-5 and 2012-6, destoning deeper than the commercial depth resulted in an increase in ridge density (Table 11*b*). Ridge bulk density increased from planting to harvest in all experiments and there was an overall trend for the increase in ridge density between planting and harvest to increase as destoning depth increased (Table 11*a,c*). The greater porosity created by destoning deeply was reduced by the soil consolidating naturally through gravity or slumping through rainfall.

Table 11. 2012: Effect of destoning depth on ridge bulk density (g/cm^3) in Expts 2012-1 to 2012-7. *(a)* planting, *(b)* final harvest, *(c)* change between planting and harvest

	Destoning	Experiment						
	depth	2012-1	2012-2	2012-3	2012-4	2012-5	2012-6	2012-7
(a)	1 Shallowest	0.92	1.02	1.12	1.04	1.02	1.03	0.94
	2	0.97	1.01	1.13	1.03	1.01	1.03	0.95
	3 Commercial	0.94	0.99	1.13	1.06	1.01	1.01	0.99
	4	0.97	1.02	1.12	1.04	0.99	1.05	1.00
	5	0.96	1.03	1.11	1.02	1.01	1.05	1.00
	6 Deepest	0.95	1.03	1.10	1.03	1.02	1.08	1.01
	S.E. (15 D.F.)	0.028	0.023	0.025	0.020	0.020	0.022	0.014
(b)	1 Shallowest	1.01	1.15	1.23	1.14	1.15	1.17	0.99
	2	1.11	1.15	1.27	1.13	1.15	1.16	0.99
	3 Commercial	1.10	1.13	1.27	1.18	1.14	1.16	1.04
	4	1.14	1.18	1.26	1.16	1.16	1.24	1.06
	5	1.12	1.18	1.25	1.16	1.19	1.22	1.07
	6 Deepest	1.10	1.19	1.26	1.18	1.21	1.27	1.08
	S.E. (15 D.F.)	0.032	0.023	0.020	0.014	0.017	0.028	0.016
(c)	1 Shallowest	0.09	0.13	0.11	0.10	0.13	0.14	0.05
	2	0.14	0.14	0.14	0.10	0.14	0.13	0.04
	3 Commercial	0.16	0.14	0.14	0.12	0.13	0.15	0.04
	4	0.17	0.16	0.14	0.12	0.17	0.19	0.06
	5	0.16	0.15	0.14	0.14	0.18	0.17	0.07
	6 Deepest	0.15	0.16	0.16	0.15	0.19	0.19	0.07
	S.E. (15 D.F.)	0.004	0.004	0.003	0.002	0.003	0.003	0.001

The rate of change in ridge bulk density between planting and final harvest with increase destoning depth was similar for all soil types, but the changes were smallest on the well-structured clay loam soil (Expt 2012-7; Figure 9)

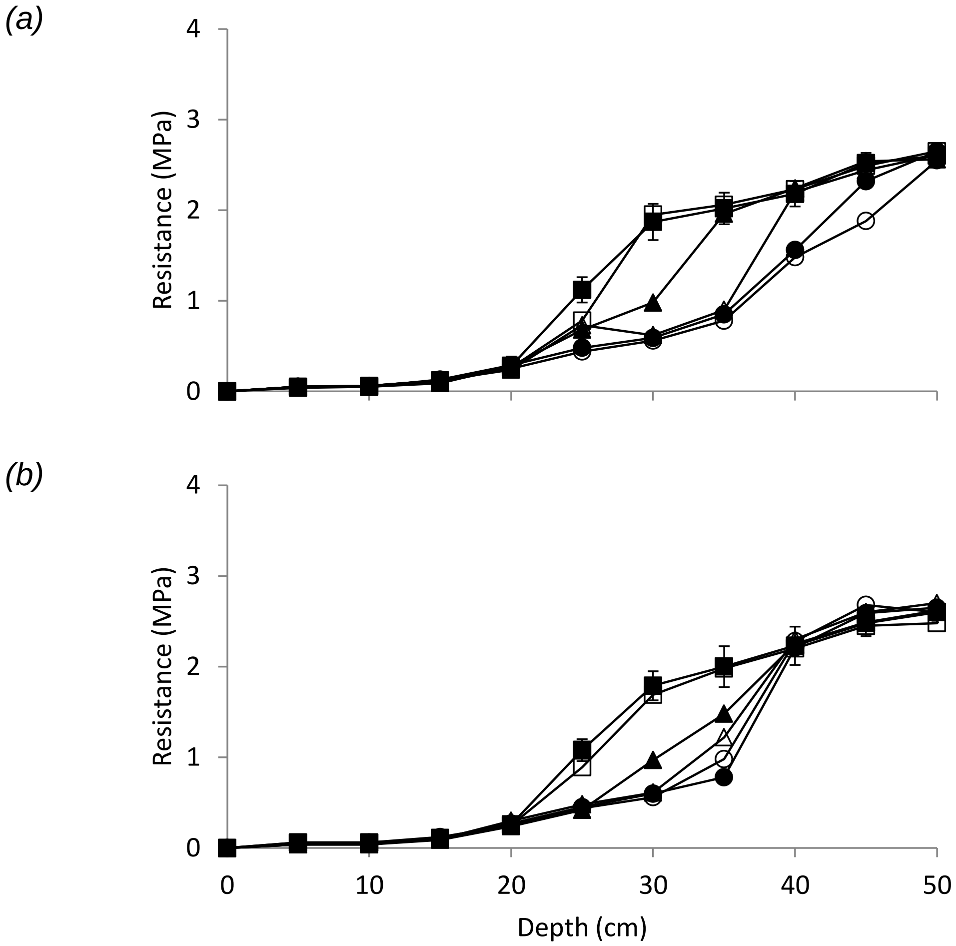
Figure 9. 2012: Change in ridge bulk density between planting and final harvest. Expts 2012-1 to 2012-6, ■, y = 0.0019 (±0.00061) x + 0.0737, R^2 = 0.49; Expt 2012-7, □; y = 0.0015 (±0.00039) x + 0.0161, R^2 = 0.66.



4.1.4.4. Penetration resistance

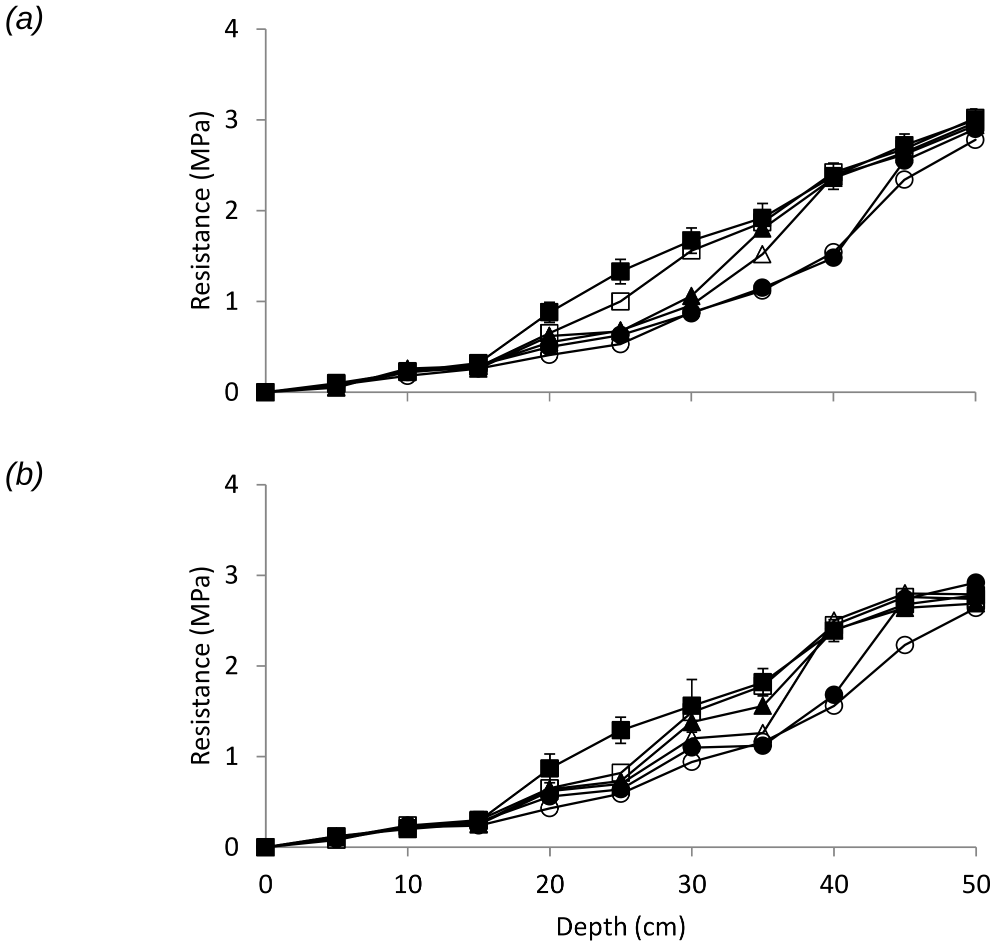
Soil resistance was measured within two days of planting and in Expt 2012-1, there was a considerable reduction in soil resistance with increase in destoning depth (Figure 10*a*). In Expt 2012-2, there was a decrease in resistance with increasing depth up to the commercial depth but destoning deeper resulted in a reduction in the volume of very loose soil in the seedbed (Figure 10*b*).

Figure 10. 2012: Effect of destoning depth on soil resistance at planting in (*a)* Expt 2012-1 and *(b)* Expt 2012-2. Depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. S.E. bars based on 15 D.F.



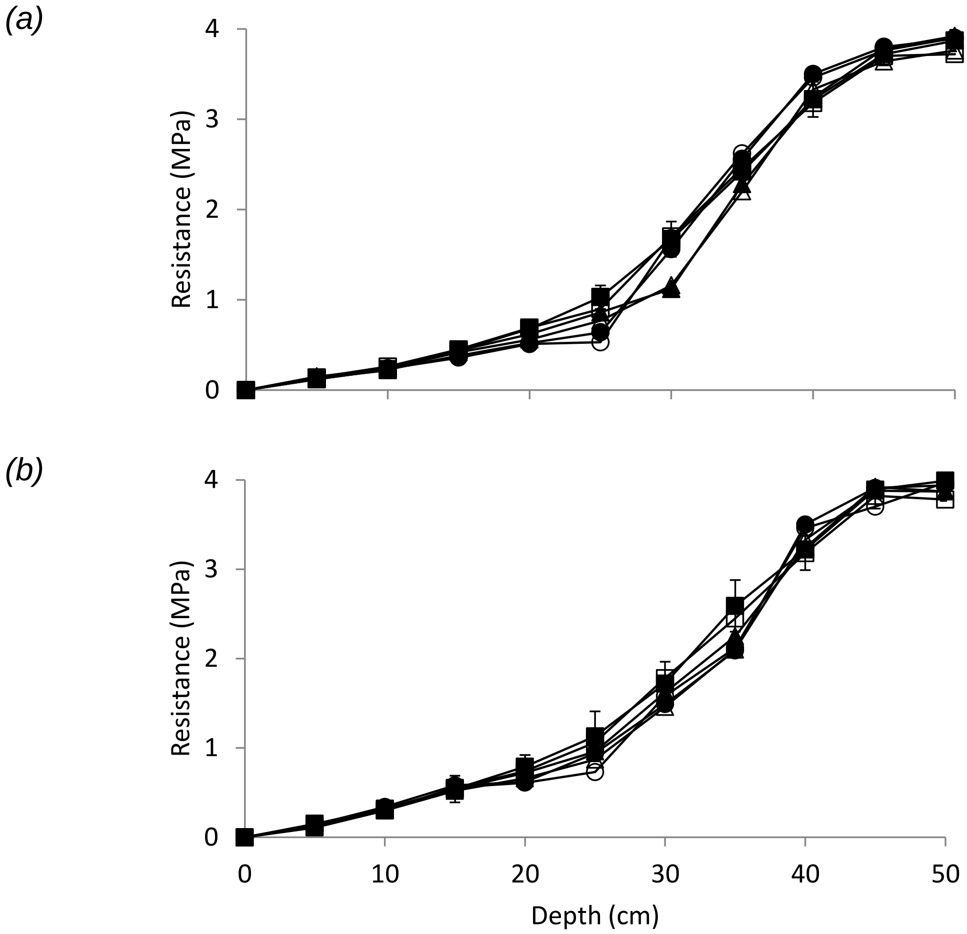
In Expts 2012-3 and 2012-4, there was a similar pattern of reduction in resistance with increase in destoning depth to Expt 2012-1. Large reductions in resistance were found by destoning to depths greater than those used commercially (Figure 11).

Figure 11. 2012: Effect of destoning depth on soil resistance at planting in *(a)* Expt 2012-3 and *(b)* Expt 2012-4. Depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. S.E. bars based on 15 D.F.



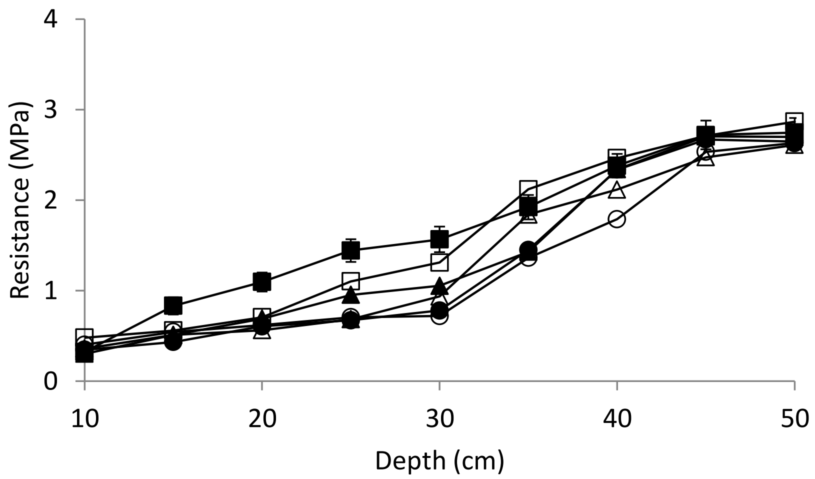
The stone content in the soil in Expts 2012-5 and 2012-6 made it difficult to obtain accurate resistance readings but the soil was much harder to penetrate after planting than in the other experiments (Figure 12). In Expt 2012-5, destoning deeper than the commercial depth (38 cm) resulted in an increased resistance below 30 cm than when destoning shallower but destoning at 30 or 38 cm resulted in the lowest overall profile resistance (Figure 12*a*). In Expt 2012-6, there was no significant effect of destoning depth on soil resistance owing to the stone content of the soil but similar trends to Expt 2012-5 were observed i.e. pan creation by destoning deeper than 40 cm (Figure 12*b*).

Figure 12. **2012: Effect of destoning depth on soil resistance at planting in *(a)* Expt 2012-5 and *(b)* Expt 2012-6. Depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. S.E. bars based on 15 D.F.**



In Expt 2012-7, as destoning depth increased from 18 to 25 cm, resistance in the top 25 cm decreased, whereas cultivating deeper than this did not reduce the resistance in the ridge any further (Figure 13). Resistance was reduced between 30 and 40 cm below the top of the ridge by destoning at 30 and 36 cm. There was little evidence of a pan being created at planting by destoning deeper than the commercial depth (25 cm).

Figure 13. 2012: Effect of destoning depth on soil resistance at planting in Expt 2012-7. Depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. S.E. bars based on 15 D.F.



4.1.4.5. Ped size distribution

In experiments sited on the sandiest soils (Expts 2012-1, 2012-3 & 2012-4), mean ped size was small (5-7 mm) and destoning depth had no effect (Table 12). On the soils with >20 % clay content (Expts 2012-2, 2012-5, 2012-6 & 2012-7), increasing destoning depth generally increased mean ped size but the effect was most marked between the shallowest and the commercial depth, with smaller increases thereafter (Table 12). The same effects of soil type and destoning depth were observed in the proportion of peds >6 mm in diameter, with shallow depths producing a smaller proportion of large peds (Table 13). The deeper destoned treatments on heavy soil most commonly had a greater proportion of very large (>35 mm diameter) peds than shallow-destoned treatments.

Table 12. 2012: Effect of destoning depth on mean ped size (mm) in the ridge at final harvest in Expts 2012-1 to 2012-7

	Destoning depth						
Expt	1 Shallowest	2	3 Commercial	4	5	6 Deepest	S.E. (15 D.F.)
2012-1	4.9	5.2	5.4	4.8	4.7	4.5	0.26
2012-2	14.1	14.4	15.5	16.3	16.1	16.7	0.64
2012-3	5.7	5.6	5.4	5.9	6.6	6.8	0.29
2012-4	6.1	5.8	6.0	6.2	6.7	6.5	0.25
2012-5	10.3	11.6	12.7	13.0	12.7	13.2	0.60
2012-6	11.3	12.0	13.1	13.2	12.8	13.0	0.54
2012-7	9.6	10.2	11.0	12.2	12.0	12.6	0.38

Table 13. 2012: Effect of destoning depth on the proportion of peds >6 mm diameter (% weight) in the ridge at final harvest in Expts 2012-1 to 2012-7

	Destoning depth						
Expt	1 Shallowest	2	3 Commercial	4	5	6 Deepest	S.E. (15 D.F.)
2012-1	23.4	23.6	22.9	22.9	23.5	23.0	1.05
2012-2	60.7	61.1	60.5	66.5	64.1	68.2	2.33
2012-3	30.0	27.9	27.4	27.4	27.2	28.8	0.88
2012-4	32.1	31.6	33.1	33.0	34.9	33.8	0.78
2012-5	52.8	54.5	58.4	60.9	60.0	61.5	2.87
2012-6	56.1	58.2	60.3	65.0	63.5	64.0	3.00
2012-7	49.8	52.2	54.7	56.2	56.2	59.9	1.98

4.1.5. Planting depth and emergence

With the exception of Expt 2012-6, the intended target commercial planting depth was generally achieved for all depths of destoning in all experiments, even for very shallow destoning (Table 14). The coefficient of variation in planting depth was not affected by destoning depth, indicating that a consistent depth of soil for accurate planting was achieved. Shallow destoning did not lead to variable planting depth as is often reported when it is difficult to achieve adequate soil depth within beds. Generally, where there was a large difference in texture between the experiments within the same field, the experiments in the heavy soil areas were planted slightly shallower than the lighter areas and there was a greater variation in planting depth along the rows. In the light area of Papworth Bungalow field (Expt 2012-3), the shallowest destoning depth resulted in shallower planting but only *c*. 1 cm less than the target depth (Table 14). In Expt 2012-6, destoning in the sandy clay loam/clay loam soil was difficult owing to the wetness of the soil and the planter driver could not obtain sufficient soil from any of the destoned beds to plant at a depth of 14 cm. In the two deepest-destoned treatments, planting depth was variable and ≤ 10 cm (Table 14). In Expt 2012-7, there was a trend for deep (>30 cm) destoning depths to result in shallower planting but there was little variation between the shallowest and commercial depths (Table 14).

Table 14. 2012: Effect of destoning depth on planting depth (cm) in Expts 2012-1 to 2012-7

		Destoning depth						
Expt	Target	1 Shallowest	2	3 Commercial	4	5	6 Deepest	S.E. 15 D.F
2012-1	18	19.0	19.4	18.9	20.2	18.0	19.7	0.47
2012-2	16	16.4	15.2	14.5	16.7	16.1	15.1	0.96
2012-3	15	13.8	16.0	16.0	16.4	15.7	15.8	0.54
2012-4	15	14.2	14.0	14.9	15.8	14.6	15.9	0.60
2012-5	14	13.6	13.8	14.0	13.7	13.2	13.3	0.71
2012-6	14	10.3	10.4	9.9	9.4	9.1	8.7	0.59
2012-7	17	16.0	15.8	17.0	16.0	15.3	14.8	0.71

As might be expected from a generally consistent planting depth, the interval from planting to emergence was not affected by destoning depth in most experiments. In Expts 2012-1 and 2012-2, 50 % emergence was 54 ± 0.5 days after planting for all destoning depths and there were similar numbers of plants emerged in all strips used to measure emergence, irrespective of depth of cultivation or soil type. In Expts 2012-3 and 2012-4, there was no effect of soil type or destoning depth on interval from planting to 50 % emergence (51 ± 0.5 days). In Expts 2012-5 and 2012-6, the interval to reach 50 % plant emergence was the same (54 ± 0.6 days), irrespective of the difference in soil type between experiments but whilst a consistent final number of plants was achieved in the 5 m measured lengths of row in the light area (Expt 2012-5), in Expt 2012-6, 7-20 % of plants failed to emerge in some plots. The non-emergence appeared to be random and not associated with any destoner depth treatment although there were fewer misses in the two shallowest and the deepest depths. Observations when counting plants at emergence in Expt 2012-6 indicated that some tubers were planted very shallowly (< 7 cm) in plots with deep destoning and these largely failed to produce viable plants. In Expt 2012-7, 50 % emergence was 41 ± 0.4 days after planting for all destoning depths.

4.1.6. Tuber yield

4.1.6.1. Cultivation depth experiments

Unlike 2011, where there was no effect of destoning depth on yield, on the heavier sites in 2012 yield was affected by the depth at which beds were cultivated. In the pair of Experiments at Greenvale AP Raveningham, there was a significant decrease in yield and number of tubers as cultivation depth increased in the heavier area (Expt 2012-2) but in the coarser-textured area (Expt 2012-1), there was no effect of depth of destoning (Table 15). There was no effect of cultivation depth on number of tubers or tuber [DM].

Table 15. 2012: Yield, number of tubers >10 mm and tuber [DM] in Expts 2012-1 and 2012-2 (harvested 17 September)

Expt	Destoning depth	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
2012-1	1 Shallowest	67.6	459	24.8
	2	67.9	467	24.4
	3 Commercial	65.7	473	24.3
	4	65.7	466	24.6
	5	64.6	456	24.8
	6 Deepest	65.0	469	25.0
	S.E. (15 D.F.)	2.81	22.1	0.71
2012-2	1 Shallowest	79.3	729	24.0
	2	76.6	745	23.4
	3 Commercial	71.7	730	23.6
	4	69.1	686	23.3
	5	66.9	667	24.2
	6 Deepest	61.8	632	23.2
	S.E. (15 D.F.)	3.19	38.2	0.77

In Expt 2012-3, although there was no significant difference in yield across destoning depths, yields were numerically lower when destoning to >45 cm depth (Table 16). In the heavier end of the field (Expt 2012-4), there was a trend for yield to decrease as destoning depth increased, although the difference was only significant between the deepest and the two shallowest depths (Table 16). There was no significant effect of cultivation depth on number of tubers or tuber [DM] but the heavier site had fewer tubers than the light (Table 16).

Table 16. 2012: Yield, number of tubers >10 mm and tuber [DM] in Expts 2012-3 and 2012-4 (harvested 11 September)

Expt	Destoning depth	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
2012-3	1 Shallowest	57.0	754	24.4
	2	56.8	811	24.5
	3 Commercial	58.1	849	23.8
	4	56.6	749	23.7
	5	52.4	752	23.5
	6 Deepest	53.2	828	24.4
	S.E. (15 D.F.)	2.87	30.6	0.60
2012-4	1 Shallowest	54.9	591	25.2
	2	55.2	646	25.3
	3 Commercial	53.9	663	24.5
	4	50.3	618	24.2
	5	50.2	646	24.2
	6 Deepest	48.0	670	23.6
	S.E. (15 D.F.)	2.28	38.8	0.59

In Expts 2012-5 and 2012-6, there was significant blackleg development during June and July which killed many plants in the experimental area. Since plots were 20 m long, harvest areas could be selected to avoid missing plants. It was observed that the number of dead or dying plants due to blackleg seemed to be greater in Expt 2012-6 than in Expt 2012-5, although the actual numbers were not recorded. Tuber [DM] was high in both experiments and associated with low fresh weight yields. In both Expt 2012-5 and Expt 2012-6, there was a trend for yield to decrease as destoning depth increased but the differences between depths were not significant (Table 17). In the heavy site (Expt 2012-6), yield was numerically greater at the two shallowest depths than at the commercial depth (35 cm). In contrast with Expts 2012-3 and 2012-4, there were more tubers produced in the heavy area (Expt 2012-6) than in the light area (Expt 2012-5, Table 17). Tuber [DM] was not affected by cultivation depth.

Table 17. 2012: Yield, number of tubers >10 mm and tuber [DM] in Expts 2012-5 and 2012-6 (harvested 13 September)

Expt	Destoning depth	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
2012-5	1 Shallowest	35.9	433	27.6
	2	35.3	442	28.4
	3 Commercial	35.4	448	28.1
	4	33.2	441	28.6
	5	33.5	460	28.6
	6 Deepest	32.7	446	28.4
	S.E. (15 D.F.)	1.79	32.4	0.40
2012-6	1 Shallowest	40.2	543	28.3
	2	39.5	551	27.9
	3 Commercial	35.8	558	27.9
	4	36.0	555	28.2
	5	36.7	500	27.8
	6 Deepest	36.1	520	28.1
	S.E. (15 D.F.)	1.80	31.7	0.50

In Expt 2012-7, there was a trend for yield to be lower when destoning depth was deeper than the commercial depth of 22 cm, although the yield differences were not significant (Table 18). The number of tubers and [DM] were not affected by destoning depth.

Table 18. 2012: Yield, number of tubers >10 mm and tuber [DM] in Expt 2012-7 (harvested 6 September)

Destoning depth	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
1 Shallowest	48.2	444	23.9
2	48.5	468	24.5
3 Commercial	48.6	481	23.9
4	45.2	436	23.7
5	44.4	463	24.2
6 Deepest	45.1	488	24.2
S.E. (15 D.F.)	1.69	21.6	0.45

In Expt 2012-8 there was a significant reduction in yield caused by flatlifting in the spring prior to planting but the depth of rotary tillage at planting had no effect (Table 19). The extra water held in the subsoil of flatlifted plots could have contributed to poor drainage and aeration in the very wet July. The number of tubers and tuber [DM] were not affected by subsoiling or bedtilling depth (Table 19).

Table 19. 2012: Yield, number of tubers >10 mm and tuber [DM] in Expt 2012-8 (harvested 27 September)

Subsoil treatment	Cultivation treatment	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
None	Shallow	63.3	446	20.8
	Deep	66.7	479	21.3
Flatlift	Shallow	54.8	433	20.8
	Deep	56.1	438	20.5
	S.E. (15 D.F.)	3.59	28.3	0.37

4.1.6.2. Nitrogen x cultivation depth experiments

In Expt 2012-9, depth of destoning had no significant effect on tuber population, tuber FW yield or tuber [DM] (Table 20). When averaged over the depth of destoning treatments, increasing the N application rate from 0 to 200 kg N/ha had no significant effect on total tuber population but increased total tuber FW yield from 39.6 to 46.4 t/ha and decreased tuber [DM] from 25.6 to 24.0 %.

Table 20. 2012: Effect of destoner depth and nitrogen application rate on tuber population, yield > 10 mm and tuber [DM] in Expt 2012-9 (harvested 28 August)

Destoned depth	N applied (kg N/ha)	Tuber population > 10 mm (000/ha)	Tuber FW yield > 10 mm (t/ha)	Tuber [DM] (%)
Shallow	0	513	40.1	25.8
	200	537	45.4	24.4
Deep	0	611	39.1	25.4
	200	554	47.3	23.6
	S.E. (15 D.F.)	29.0	1.85	0.27

In Expt 2012-10, there was a larger response to N where soil was cultivated shallow rather than deep (Table 21). In Expt 2012-11, whilst applying 200 kg N/ha increased yield, overall it did so by a smaller amount than in the experiment conducted on light soil (Expt 2012-10). There was no significant effect of cultivation depth on yield or an interaction with N application on the heavy site (Table 22).

Table 21. 2012: Yield, number of tubers >10 mm and tuber [DM] in Expt 2012-10 (harvested 3 October)

Cultivation treatment	Nitrogen rate (kg/ha)	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
Shallow	0	33.5	417	27.2
	200	49.5	462	27.1
Deep	0	36.5	441	27.0
	200	43.3	437	27.3
	S.E. (6 D.F.)	2.01	30.8	0.51
	S.E. same Cult (6 D.F.)	2.03	29.2	0.46

Table 22. 2012: Yield, number of tubers >10 mm and tuber [DM] in Expt 2012-11 (harvested 3 October)

Cultivation treatment	Nitrogen rate (kg/ha)	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
Shallow	0	53.4	516	25.4
	200	58.4	510	25.7
Deep	0	49.1	505	25.0
	200	58.3	498	24.9
	S.E. (4 D.F.)†	2.34	27.0	0.19
	S.E. same Cult (4 D.F.)	3.14	27.0	0.26

†One replicate missing due to blight infection

4.1.6.3. *Planter profile experiments*

In Expt 2012-12, there was no effect of destoning aggressiveness, bed profile or planter hood pressure on total or graded yield, number of tubers or tuber [DM] (Table 23).

Table 23. 2012: Yield, number of tubers >10 mm and tuber [DM] in Expt 2012-12 (harvested 18 September)

Destoning pitch	Profile	Hood pressure	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
Coarse	Flat	Low	41.1	825	17.6
		High	40.1	851	18.2
	Ridge	Low	42.5	879	17.8
		High	42.3	934	18.1
Fine	Flat	Low	39.7	852	17.6
		High	42.3	848	17.1
	Ridge	Low	40.4	834	17.1
		High	43.9	879	16.4
		S.E. (14 D.F.)	1.42	65.7	0.86

4.1.7. Soil mineral nitrogen and nitrogen uptake

In Expt 2012-9, destoning depth had no significant effect on SMN at any position across the bed when measured on 20 June (Table 24) and the mean SMN was 74 kg N/ha (compared with 134 kg N/ha in 2011). At final harvest, the average SMN to 90 cm depth was 30 kg N/ha (compared with 37 kg N/ha in 2011) and, again depth of destoning had no significant effect on the amount of N at any position across the bed profile.

Table 24. 2012: Effect of destoner depth and sampling position on soil mineral nitrogen (kg N/ha, 0-90 cm) on two occasions in Expt 2012-9

Date of sampling	20 June		28 August	
Destoner depth	Shallow	Deep	Shallow	Deep
In centre of bed ('A')	80	74	26	23
Between adjacent plants ('B')	121	92	29	22
In wheeling	30	48	24	58
Mean of destoner depth	77	72	26	34
Grand mean	74		30	
S.E. (10 D.F.; destoner depth)	6.7		4.1	
S.E. (10 D.F.; destoner depth × position)	11.7		7.1	

Final harvest in Expt 2012-9 was on the 28 August when plots that had received 200 kg N/ha were still at *c.* 100 % ground cover and the unfertilized plots had *c*. 75 % ground cover. Depth of destoning had no significant effect on tuber or total DM yield but increasing the N application rate from 0 to 200 kg N/ha increased tuber DM yield by *c*. 1 t/ha and total DM yield by *c*. 2.5 t/ha (Table 25). Destoning depth had no significant effect on either tuber of total N uptake as was found in a similar experiment with the variety Linton in 2011. When averaged over the shallow and deep destoning treatments, tuber N uptake was increased from 88 to 160 kg N/ha when the N application rate was increased from 0 to 200 kg N/ha. Similarly, increasing the N application rate from 0 to 200 kg N/ha increased total N uptake from 117 to 229 kg N/ha. The mean 112 kg N/ha increase in N uptake as a result of applying 200 kg N/ha indicates a fertilizer use efficiency of 56 % which is a fairly typical value for potatoes. The absence of any effect of destoning depth on N uptake is consistent with the cultivation having little consistent effect on SMN. This experiment was planted on a soil with a relatively low organic matter (1.3 %) and for the purposes of N recommendations, this field would be placed in Soil Supply Index 0 or 1 and therefore might be expected to supply < 80 kg N/ha to the crop. However, measurements of total N uptake of the crops that received no N fertilizer showed that the soil N supply was larger than expected. The N uptake of the unfertilized crop of Linton in a similar experiment in 2011 was almost identical (119 kg N/ha).

Table 25. 2012: Effect of destoner depth and nitrogen application rate on tuber and total DM yield and nitrogen uptake in Expt 2012-9

Destoner depth	Shallow		Deep		S.E.
N application rate (kg N/ha)	0	200	0	200	(15 D.F.)
Tuber DM yield (t/ha)	10.3	11.1	9.9	11.2	0.48
Total DM yield (t/ha)	12.1	14.2	11.7	14.6	0.54
Tuber N uptake (kg N/ha)	85	148	90	173	6.8
Total N uptake (kg N/ha)	116	215	119	244	9.3

4.1.8. Tuber quality

Assessments of tuber quality were made for all experiments. There was avery low incidence of greening, cracking and common scab and there were no significant effects of destoning depth. Alongside the experiments and in other fields, simple comparisons of destoning depth and aggressiveness were made. Table 26 shows the incidence of common scab in destoning aggressiveness trials conducted in commercial fields. There was no effect of web or star pitch or web or rotor speed on the severity of scab despite visual differences in the proportion of clod remaining on the surface of the ridge post-planting. There was little effect of destoning aggressiveness on ped size distribution in the majority of these trials (see Section **4.1.4.5**) but in Stevenson Harriets there was a significant increase of 8 % in ped size in the Coarse treatment compared with Fine with no effect of common scab (or greening).

Table 26. 2012: Severity of common scab (% SA) in commercial trials

Grower-Field	Variety	Fine tilth	Coarse tilth	S.E. (4 D.F.)
Papworth Felmingham 14	Maris Piper	2.92	2.28	1.140
Papworth Sco Marlers	Maris Piper	0.73	1.21	0.209
GVAP Black Barn	Maris Piper	0.90	0.99	0.170
GVAP Norton L	Maris Piper	0.73	0.70	0.145
GVAP Norton H	Maris Piper	0.73	0.87	0.169
Greenseed Banns	Annabelle	0.56	0.56	0.024
EJ Andrews 300A	Desiree	0.69	0.60	0.099
Stevenson Harriets	Desiree	0.58	0.61	0.169

4.2. 2013

4.2.1. Actual depths of destoning

As in 2013, the actual depth of the destoned bed prior to planting compared with intended varied across experiments in relations to soil type. In contrast to 2012, there was only one experiment (Expt 2013-2) where working deeper resulted in considerably less soil ending up in the finished bed than with the planned depth (Table 27). As in 2012, the destoner depths will be referred to as depths 1…6 and by reference to Table 27, the true depth of bed can be determined for experiments conducted in 2013.

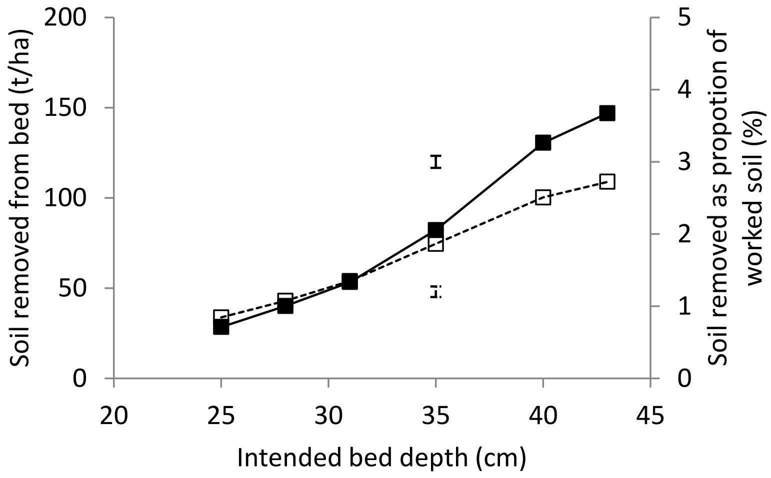
Table 27. 2013: Intended and actual achieved depth (cm) of destoning in Expts 2013-1 to 2013-8

		Depth					
Expt	Intended (I) vs Actual (A)	1 Shallowest	2	3	4 Commercial	5	6 Deepest
2013-1	I	24	27	30	35	42	49
	A	26	29	34	41	45	48
2013-2	I	24	27	30	32	35	39
	A	24	26	29	33	36	34
2013-3	I	25	28	31	35	40	43
	A	27	31	33	37	43	45
2013-4	I	25	28	31	35	40	43
	A	28	32	33	37	43	45
2013-5	I	20	22	24	26	29	33
	A	23	25	27	28	29	35
2013-6	I	20	22	24	26	29	33
	A	22	23	24	25	27	32
2013-7	I	18	22	-	26	-	30
	A	20	25	-	27	-	31
2013-8	I	-	26	30	35	-	41
	A	-	26	30	35	-	41

4.2.2. Soil removed from bed during destoning

In Expt 2013-4, the weight of soil and stones removed from the bed and deposited into the adjacent wheeling was measured. At shallow depths, the material sieved out was largely stone rather than clod but as depth of destoning increased beyond 35 cm, increasingly more clod was deposited in the furrow (Figure 14). There was not the marked change at one particular depth in the amount of clod removed from the bed as found with Expts 2012-5 and 2012-6.

Figure 14. 2013: Quantity of soil removed from bed (solid line and solid symbols) and proportion of soil transferred to furrow (dashed line and open symbols) during destoning in Expt 2013-4. S.E. bars based on 15 D.F.



4.2.3. Rate of work and fuel consumption

The spot forward speeds of the different destoner depth treatments are shown in Table 28, the spot rates of work in Table 29 and the fuel consumption during destoning in Table 30. Rate of work decreased with depth, except in Expt 2013-8 where the speed was fixed. The shallowest depth of destoning ranged from 21-78 % faster than the commercial depth and even the second shallowest depth was 13-59 % faster than the commercial depth (Table 28, Table 29). However, the variation in speed was greater between fields than for different depths within a field, with the heavier soils not always being the slowest (e.g. Expts 2013-5 and 2013-6). Growers whose fields were used in Expts 2013-5 to 2013-7 were aware of the risk of compaction on their heavy soils and the commercial depth of destoning was shallower (26-28 cm) than the lighter soils (33-36 cm). When comparing 26-28 cm depths on lighter soils, speeds ranged from 2.8-4.4 km/h and rates from 0.54-0.80 ha/h, so the rates in the clay soils were at the lower end of the range of rates in sandy soils. Fuel consumption increased with depth, being 15-61 % greater at the commercial depth than the shallowest and 6-39 % greater than at the second shallowest depth (Table 30). Again, cultivation on the heaviest soils (Expts 2013-5 and 2013-6), consumed less fuel than on the lighter sites as the destoning depth was shallower.

Table 28. 2013: Spot forward speeds (km/h) of destoner treatments in Expts 2013-1 to 2013-8

	Depth of destoning					
Expt	1 Shallowest	2	3	4 Commercial	5	6 Deepest
2013-1	3.2	2.8	2.7	2.3	1.7	1.5
2013-2	1.2	1.0	0.9	0.7	0.7	0.6
2013-3	4.9	4.4	3.0	2.8	2.5	2.2
2013-4	3.2	2.8	2.5	2.4	2.2	1.8
2013-5	4.8	4.3	3.7	2.7	2.1	1.4
2013-6	4.7	4.3	3.7	2.8	2.1	1.4
2013-7†	2.8	2.6	-	2.3	-	1.8
2013-8	-	1.9	1.9	1.9	-	1.9

†Combined destoner and bedtiller operation

Table 29. 2013: Spot rates of work (ha/h) of destoner treatments in Expts 2013-1 to 2013-8

	Depth of destoning					
Expt	1 Shallowest	2	3	4 Commercial	5	6 Deepest
2013-1	0.62	0.54	0.52	0.44	0.33	0.29
2013-2	0.23	0.18	0.17	0.14	0.13	0.11
2013-3	0.89	0.80	0.55	0.51	0.46	0.40
2013-4	0.59	0.52	0.45	0.43	0.40	0.32
2013-5	0.87	0.79	0.68	0.49	0.38	0.25
2013-6	0.86	0.79	0.68	0.50	0.38	0.25
2013-7†	0.51	0.48	-	0.42	-	0.34
2013-8	-	0.35	0.35	0.35	-	0.35

†Combined destoner and bedtiller operation

Table 30. 2013: Fuel consumption (l/ha) of destoner treatments in Expts 2013-3 to 2013-8

	Depth of destoning					
	1	2	3	4	5	6
Expt	Shallowest			Commercial		Deepest
2013-3	17.8	22.9	25.8	28.6	34.6	37.2
2013-4	23.6	28.6	30.6	35.3	37.6	48.3
2013-5	9.6	10.9	12.1	14.7	16.9	24.1
2013-6	10.2	10.8	13.5	15.0	17.3	24.2
2013-7†	46.4	52.5	-	55.4	-	68.2
2013-8	-	26.2	27.5	30.1	-	38.4

†Combined fuel costs for destoner and bedtiller

4.2.4. Soil measurements

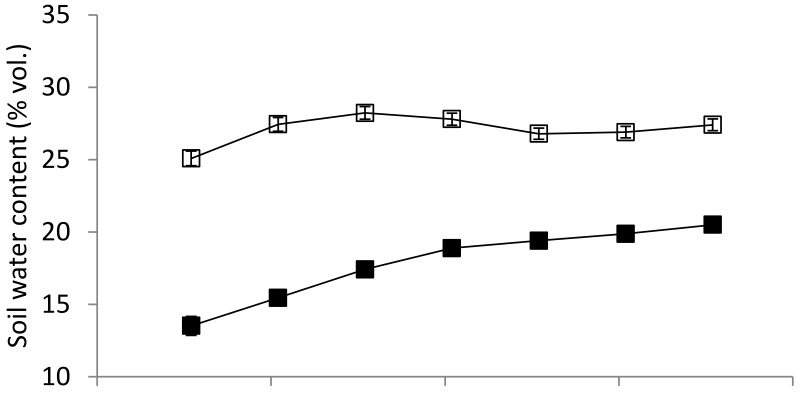
4.2.4.1. Soil water content and plastic limit

In Expt 2013-1, the soil water content in the bed prior to destoning increased from 13.5 % (vol./vol.) close to the surface of the bed to a maximum of 20.5 % at 55 cm (Figure 15*a*). The PL was relatively constant (26.8-28.2 %) with depth below 30 cm but the critical depth for cultivation (where the soil water content line crosses the PL line) was never reached owing to the low clay content and water content of the soil.

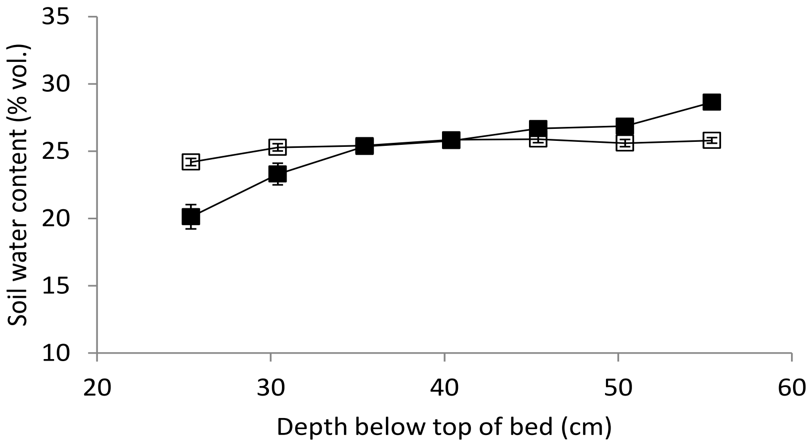
In the heavy area (Expt 2013-2), the soil was wetter in the surface of the bed (20 %) than the light area and increased progressively with depth (Figure 15*b*). The PL was again relatively constant with depth (24.2-25.8 %) but the critical depth for cultivation was reached at a depth of *c*. 35 cm from the top of the bed. Since the beds were drawn up from a flat-cultivated surface, the actual critical depth in Expt 2013-2 when related to a flat surface would be *c*. 22 cm.

Figure 15. **2013: Profile of soil water content (■) and lower plastic limit (□) in deep beds immediately prior to destoning.** ***(a)*** **Expt 2013-1;** ***(b)*** **Expt 2013-2. S.E. bars based on 15 D.F.**

(a)



(b)



In Expts 2013-3 and 2013-4, the soil was sandy and dry at planting to considerable depth, even in the heavy area of the field and the soil water content in the beds did not exceed reach the PL (typically 25-29 %) at any depth (Figure 16).

Figure 16. 2013: Profile of soil water content (■) and lower plastic limit (□) in deep beds immediately prior to destoning. *(a)* Expt 2013-3; *(b)* Expt 2013-4. S.E. bars based on 15 D.F.

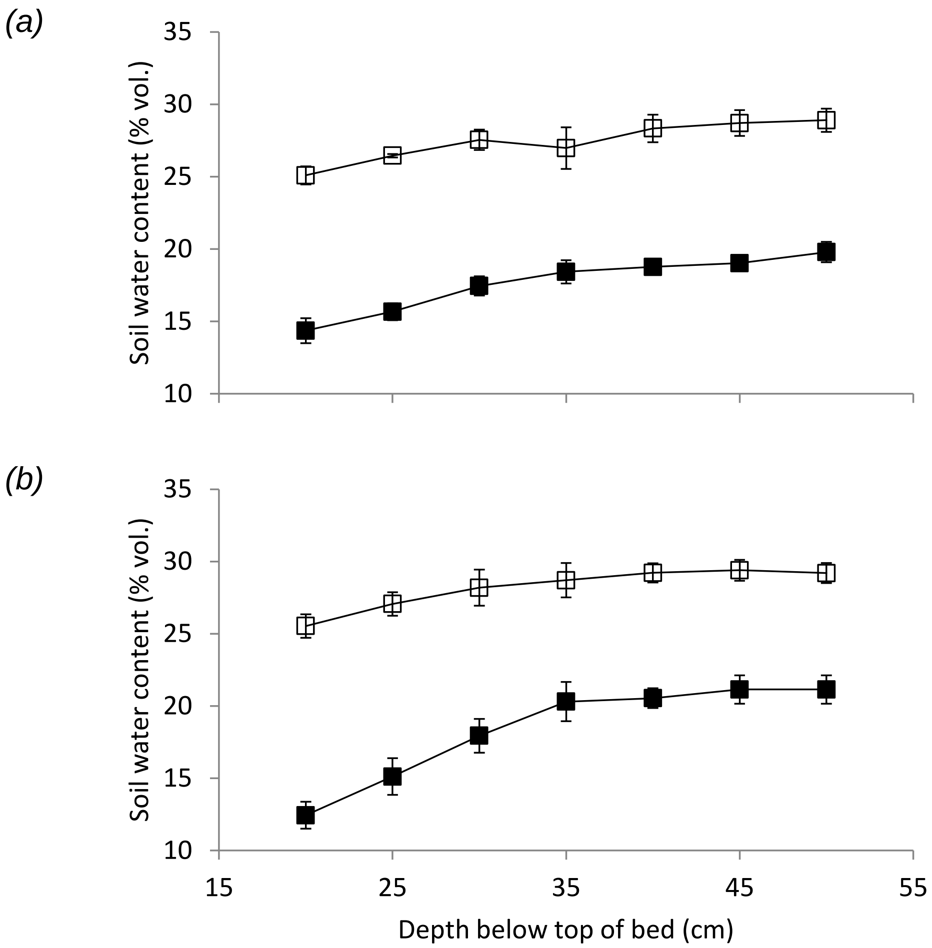
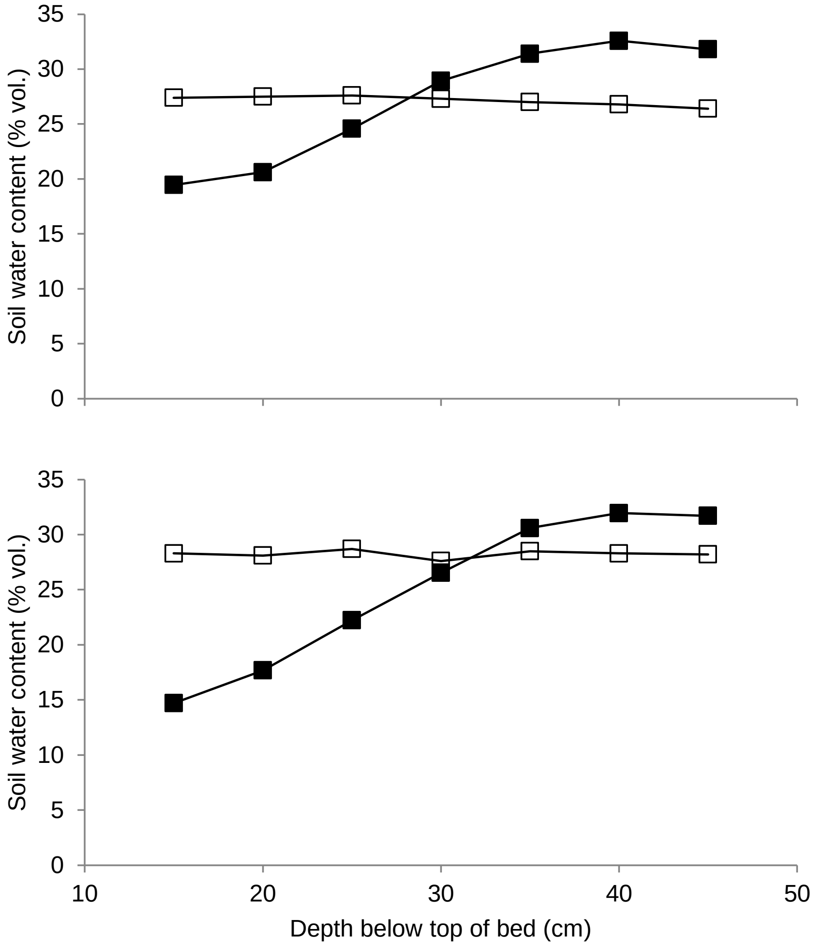


Figure 17 shows the soil water content throughout the profile in deep beds immediately prior to destoning Expts 2013-5 and 2013-6. In Expt 2013-5, the soil water content in the bed prior to destoning increased from 20 % close to the surface of the bed to a maximum of 32.6 % at 40 cm (Figure 17*a*). The PL was relatively constant with depth but the critical depth for cultivation was *c.* 28 cm from the top of the bed. In the heavy area of the same field (Expt 2013-6), the soil was drier in the surface of the bed (15 %) as it was cloddier but reached a similar water content at 40 cm as Expt 2013-5 (Figure 17*b*). The PL was again relatively constant with depth but the critical depth for cultivation was slightly deeper in Expt 2013-6 than in Expt 2013-5 at *c*. 30 cm from the top of the bed. Since the raised over-wintered beds were drawn up from a ploughed surface, the actual critical depths when related to a flat surface would be *c*. 20 cm in Expt 2013-5 and 22 cm in Expt 2013-6.

Figure 17. 2013: Profile of soil water content (■) and lower plastic limit (□) in deep beds immediately prior to destoning. *(a)* Expt 2013-5; *(b)* Expt 2013-6. S.E. bars based on 15 D.F.

(a)

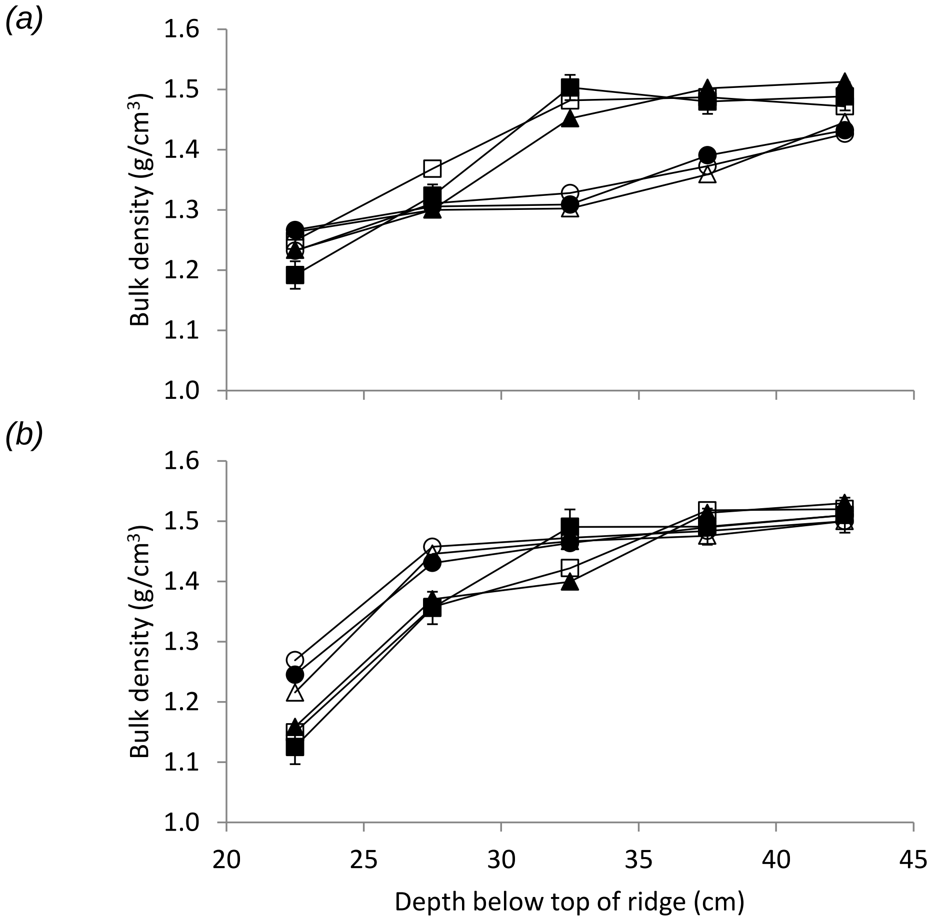
(b)



4.2.4.2. Bulk density

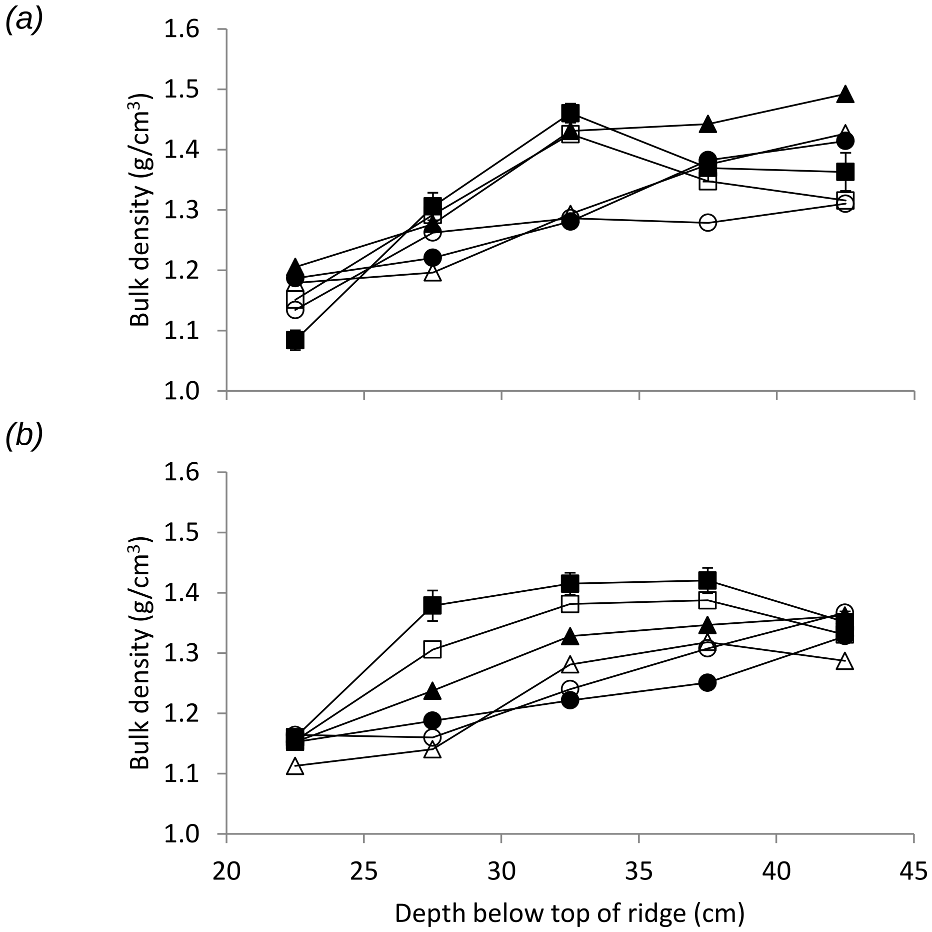
In Expt 2013-1, there was no effect of destoning depth on bulk density in the 20-25 and 25-30 cm horizons but in the 30-35 and 35-40 cm horizons the three deepest destoning depths had lower bulk densities than shallower destoning (Figure 18*a*). There was no effect of cultivation depth in the deepest horizon. In Expt 2013-2, although there was no significant effect of destoning depth on bulk density in any horizon, there was a trend for destoning depths < 30 cm to have lower bulk densities in the 25-30 and 30-35 cm horizons than deeper destoning depths (Figure 18*b*).

Figure 18. 2013: Effect of destoning depth on soil bulk density in *(a)* Expt 2013-1 and *(b)* Expt 2013-2. Depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. S.E. bars based on 15 D.F.



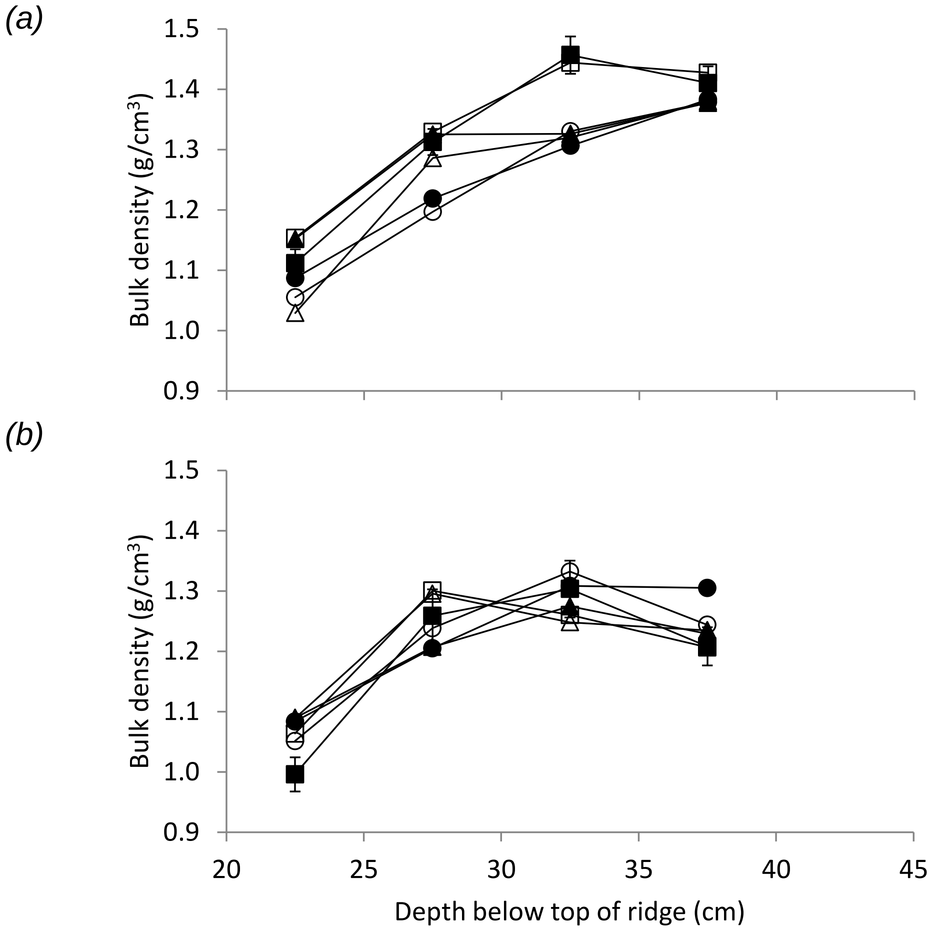
In Expt 2013-3, there was little effect of destoning depth on bulk density but at 30-35 cm soil density was greater for destoning depths shallower than 33 cm than for deeper destoning depths (Figure 19*a*). In Expt 2013-4, there was a significant trend for density to decrease with increasing destoning depth in the 25-30, 30-35 and 35-40 cm horizons (Figure 19*b*).

Figure 19. 2013: Effect of destoning depth on soil bulk density in *(a)* Expt 2013-3 and *(b)* Expt 2013-4. Depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. S.E. bars based on 15 D.F.



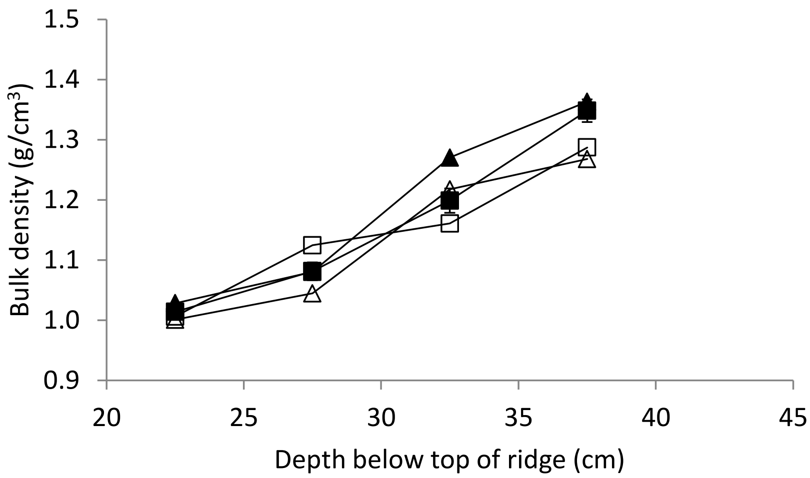
In Expt 2013-5, density was greater in the 30-35 cm horizon for the two shallowest destoning depths than deeper depths but in all other horizons cultivation depth had no effect on density (Figure 20*a*). There was no significant effect of cultivation depth in Expt 2013-6 (Figure 20*b*).

Figure 20. 2013: Effect of destoning depth on soil bulk density in *(a)* Expt 2013-5 and *(b)* Expt 2013-6. Depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. S.E. bars based on 15 D.F.



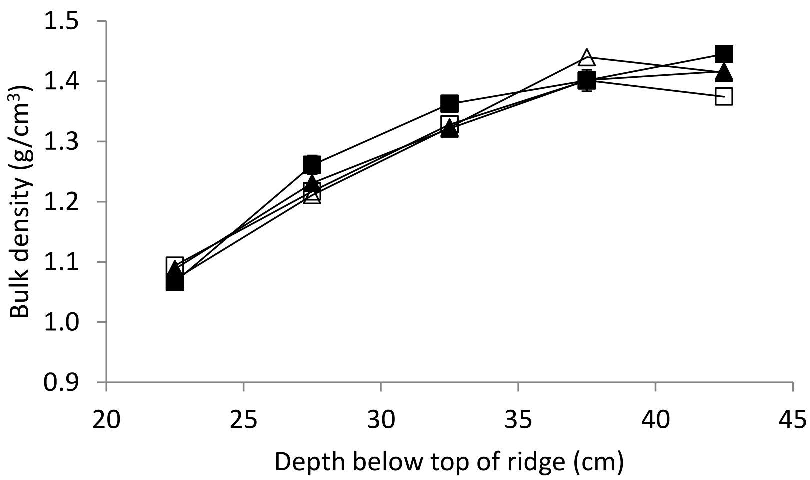
In Expt 2013-7, there was no significant effect of destoning depth on bulk density in any of the horizons measured (Figure 21).

Figure 21. 2013: Effect of destoning depth on soil bulk density in Expt 2013-7. Depth 1, ■; 2, □; 4, ▲; 6, △. S.E. bars based on 15 D.F.



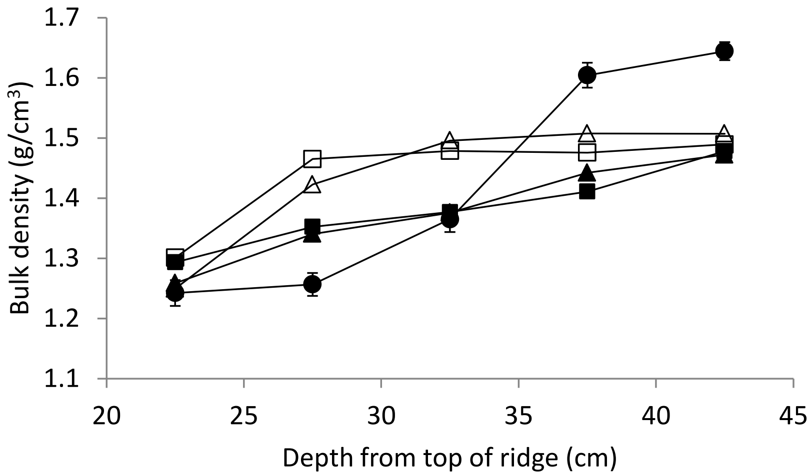
In Expt 2013-8, there was no significant effect of destoning depth on bulk density in any of the horizons measured (Figure 22).

Figure 22. 2013: Effect of destoning depth on soil bulk density in Expt 2013-8. Depth 2, ■; 3, □; 4, ▲; 6, △. S.E. bars based on 15 D.F.



Bulk densities were high in the sandy site in Expt 2013-19. Primary cultivation (plough vs Simba) prior to destoning had no effect on bulk density but shallow (25 cm) destoning produced lower bulk densities in the 25-30, 30-35 and 35-40 cm horizons than deep (35 cm) destoning (Figure 23). The Tillerstar produced a seedbed with much greater bulk density below 35 cm than shallow destoning (Figure 23), which was very obvious during core sampling.

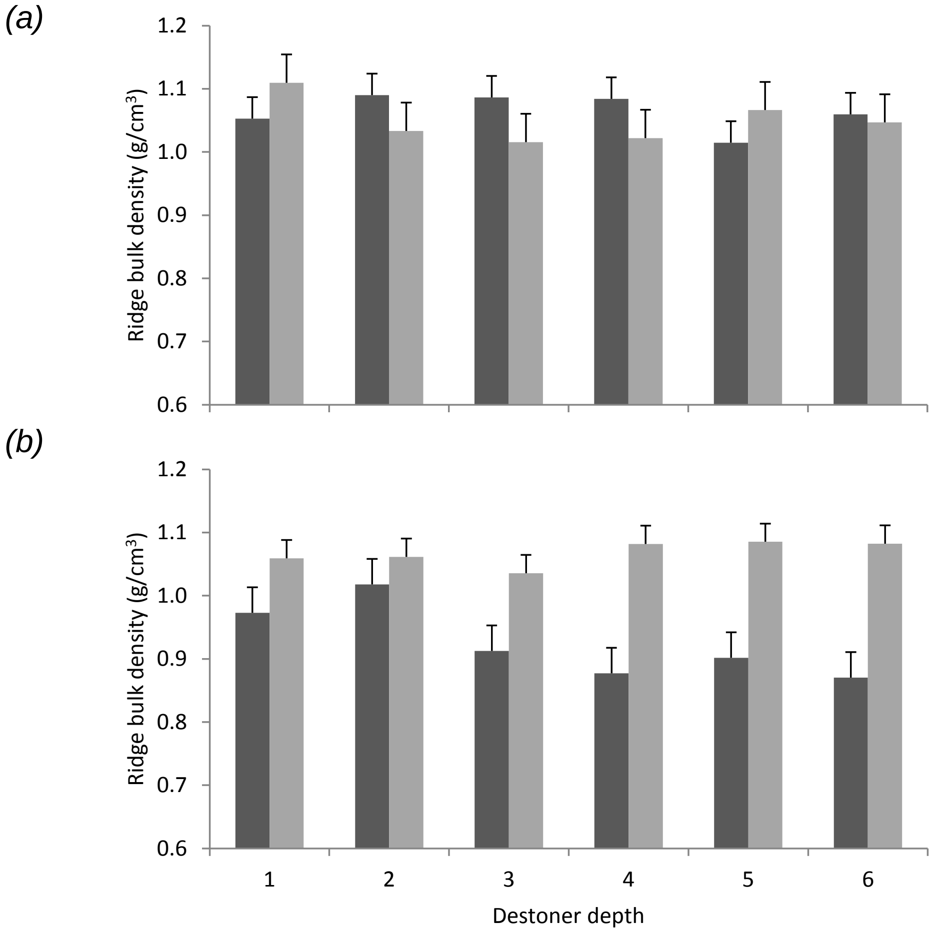
Figure 23. 2013: Effect of destoning depth on soil bulk density in Expt 2013-19. Plough 25 cm, ■; Plough 35 cm, □; Simba 25 cm, ▲; Simba 35 cm, △; Tillerstar, ●. S.E. bars based on 4 D.F.



4.2.4.3. Ridge bulk density

In both Expt 2013-1 and Expt 2013-2, there was no effect of destoning depth on ridge bulk density at either planting or harvest (Figure 24). In Expt 2013-1 on a sandy loam soil, on average, there was little change in ridge density during the season (Figure 24*a*) but in Expt 2013-2 on a sandy clay loam soil, there was a significant change in ridge density across all depth treatments which was greater in depths 3-6 than the two shallowest depths (Figure 24*b*).

Figure 24. 2013: Effect of destoning depth on ridge bulk density in *(a)* Expt 2013-1 and *(b)* Expt 2013-2. Planting, ■; Harvest, ■. S.E. bars based on 15 D.F.

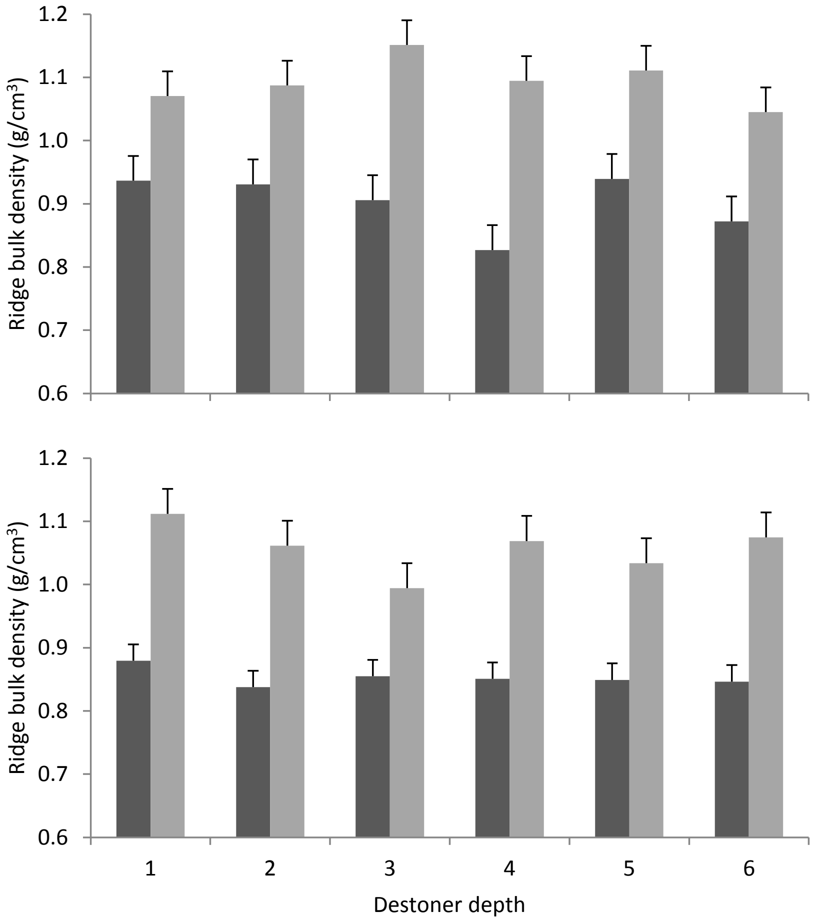


In Expt 2013-3, ridge density increased from planting to harvest but there was no effect of cultivation depth on density at either date or the change during the season (Figure 25*a*). In Expt 2013-4, there was no significant effect of destoning depth on ridge density at planting or harvest (Figure 25*b*) and the increase in density during the season (0.20 g/cm^3) was similar to Expt 2013-3 (0.19 g/cm^3)

Figure 25. 2013: Effect of destoning depth on ridge bulk density in *(a)* Expt 2013-3 and *(b)* Expt 2013-4. Planting, ■; Harvest, ■. S.E. bars based on 15 D.F.

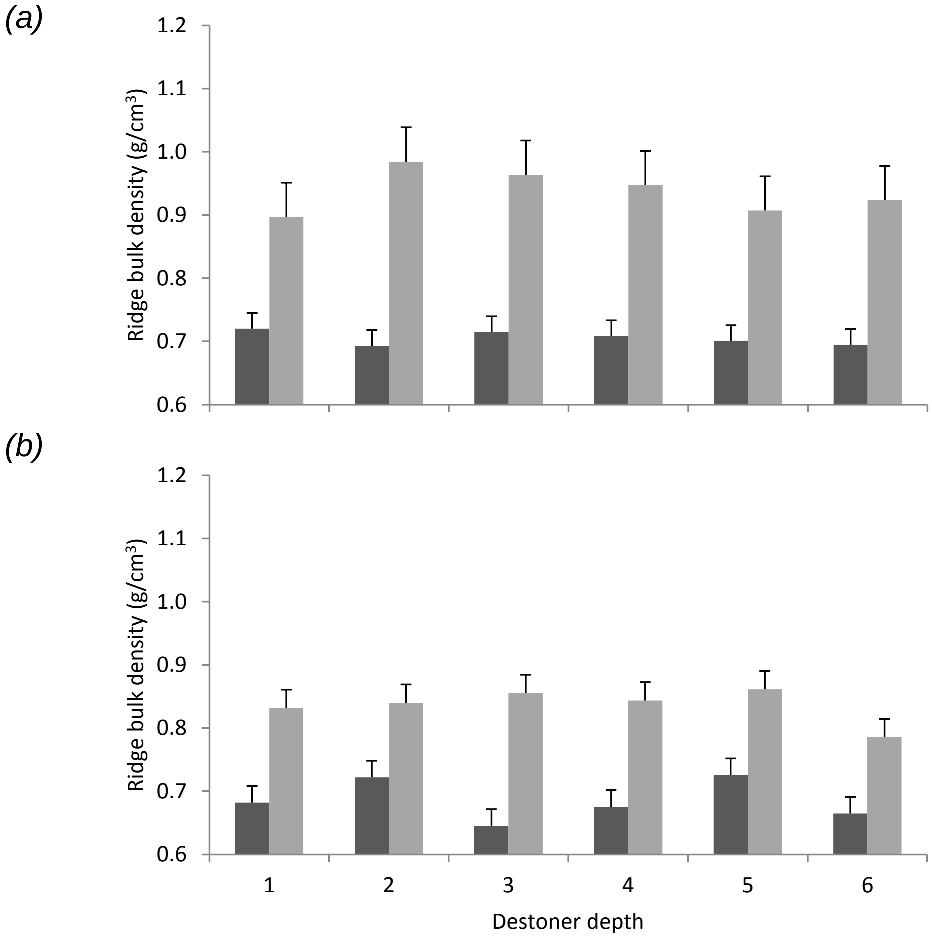
(a)

(b)



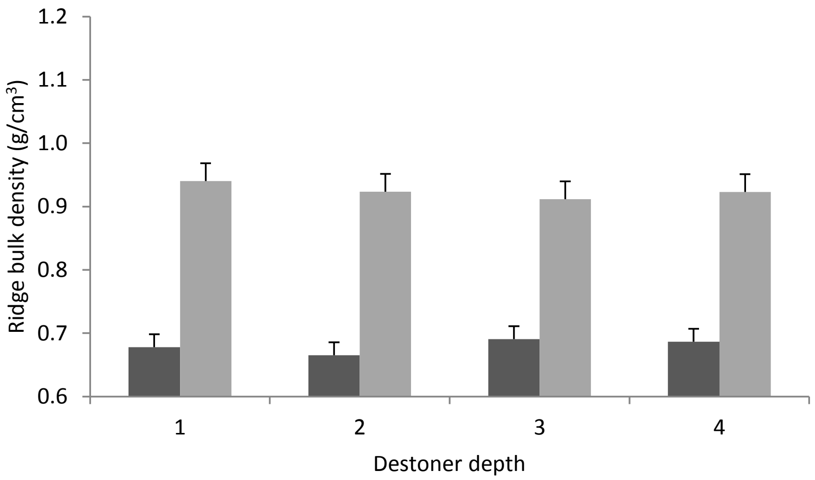
In the clay loam soils of Expts 2013-5 and 2013-6, ridge density was very low. In Expt 2013-5, ridge density increased from planting to harvest but there was no effect of cultivation depth on density at either date or the change during the season (Figure 26*a*). In the heavier area of Stevenson Mow field (Expt 2013-6), there was again no significant effect of destoning depth on ridge density at planting or harvest (Figure 26*b*) and the increase in density during the season (0.15 g/cm^3) was much smaller than in Expt 2013-5 (0.23 g/cm^3).

Figure 26. 2013: Effect of destoning depth on ridge bulk density in *(a)* Expt 2013-5 and *(b)* Expt 2013-6. Planting, ■; Harvest, ■. S.E. bars based on 15 D.F.



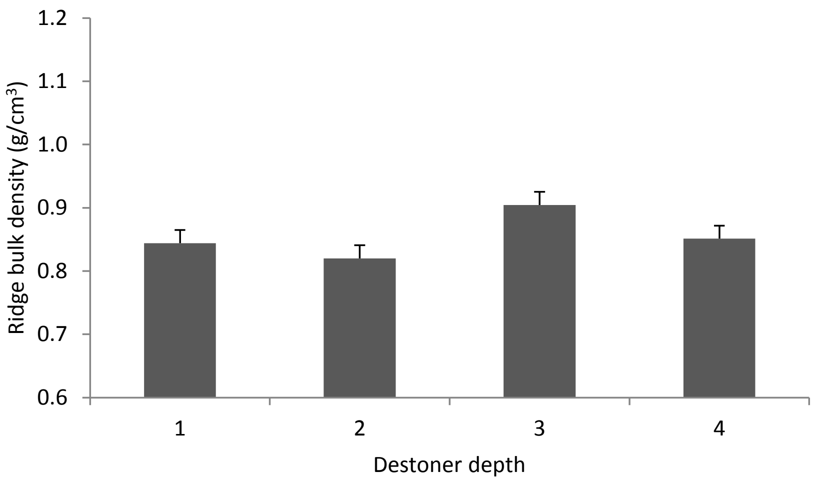
Situated on a similar soil to Expts 2013-5 and 2013-6, ridge density was very low in Expt 2013-7. Ridge density increased considerably from planting to harvest (0.24 g/cm^3) but there was no effect of cultivation depth on density at either date or the change during the season (Figure 27).

Figure 27. 2013: Effect of destoning depth on ridge bulk density in Expt 2013-7. Planting, ■; Harvest, ■. S.E. bars based on 15 D.F.



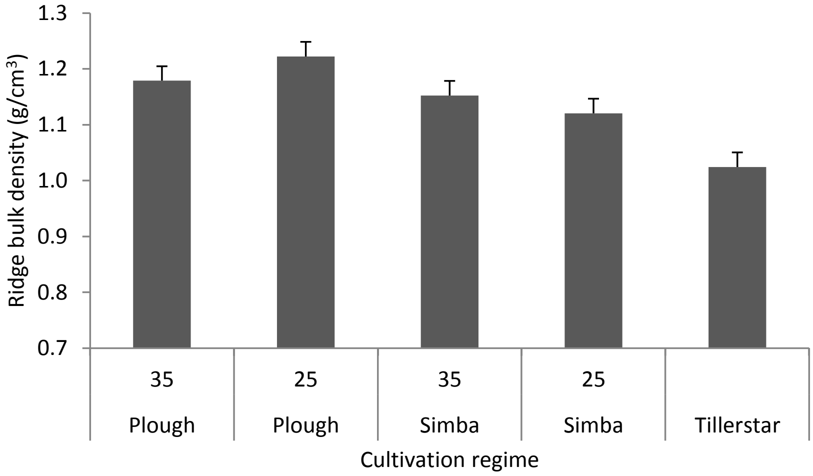
There was no effect of destoning depth on ridge density in Expt 2013-8 (Figure 28).

Figure 28. 2013: Effect of destoning depth on ridge bulk density at harvest in Expt 2013-8. S.E. bars based on 15 D.F.



In Expt 2013-19, ridge density was very high at harvest and the Tillerstar produced ridge which were lower density than the cultivation regimes using standard destoning technology (Figure 29).

Figure 29. 2013: Effect of destoning depth and primary cultivation on ridge bulk density at harvest in Expt 2013-19. S.E. bars based on 4 D.F.

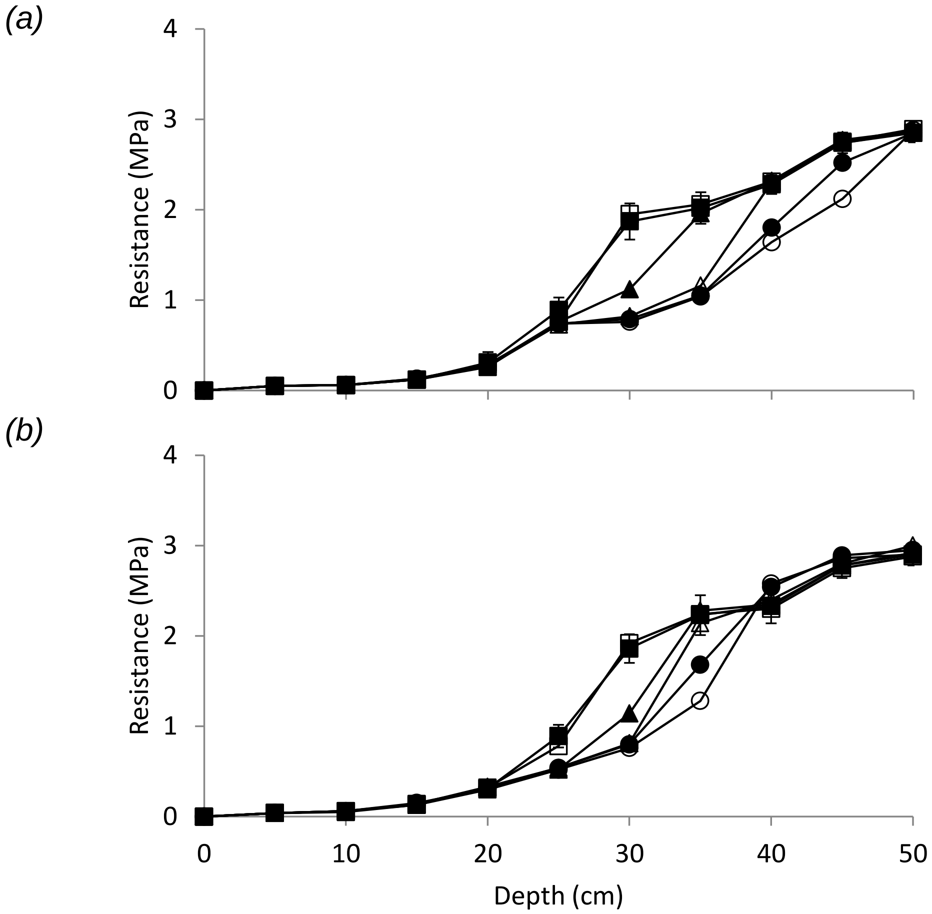


In summary, destoning depth had little effect on ridge density and densities increased from planting to harvest, with the change in density over time not being affected by cultivation regime. More clay-dominated soils had lower ridge bulk densities than sandier soils, and generally the greater the clay content, the greater the increase in density during the season. The sandiest site exhibited no change in ridge density during the season.

4.2.4.4. Penetration resistance

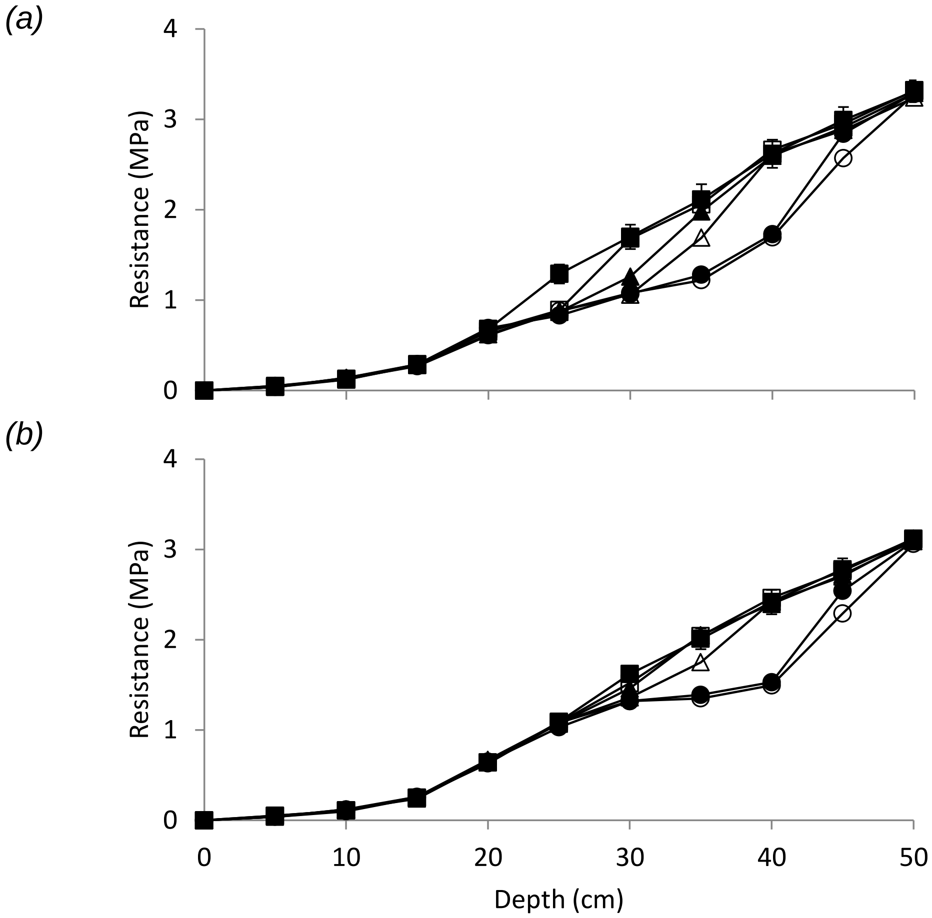
Soil resistance was measured immediately after planting. In Expt 2013-1, there was a reduction in soil resistance after planting with increase in destoning depth (Figure 30*a*). In Expt 2013-2, where the soil could not be worked as deeply, there was a decrease in resistance with increasing depth up the commercial depth but running the destoner share deeper resulted in smaller reductions in soil resistance than in the lighter soil (Figure 30*a* and *b*). There was some indication that compaction occurred at the two deepest depths but this was not significant (Figure 30*b*).

Figure 30. 2013: Effect of destoning depth on soil resistance at planting in *(a)* Expt 2013-1 and *(b)* Expt 2013-2. Depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. S.E. bars based on 15 D.F.



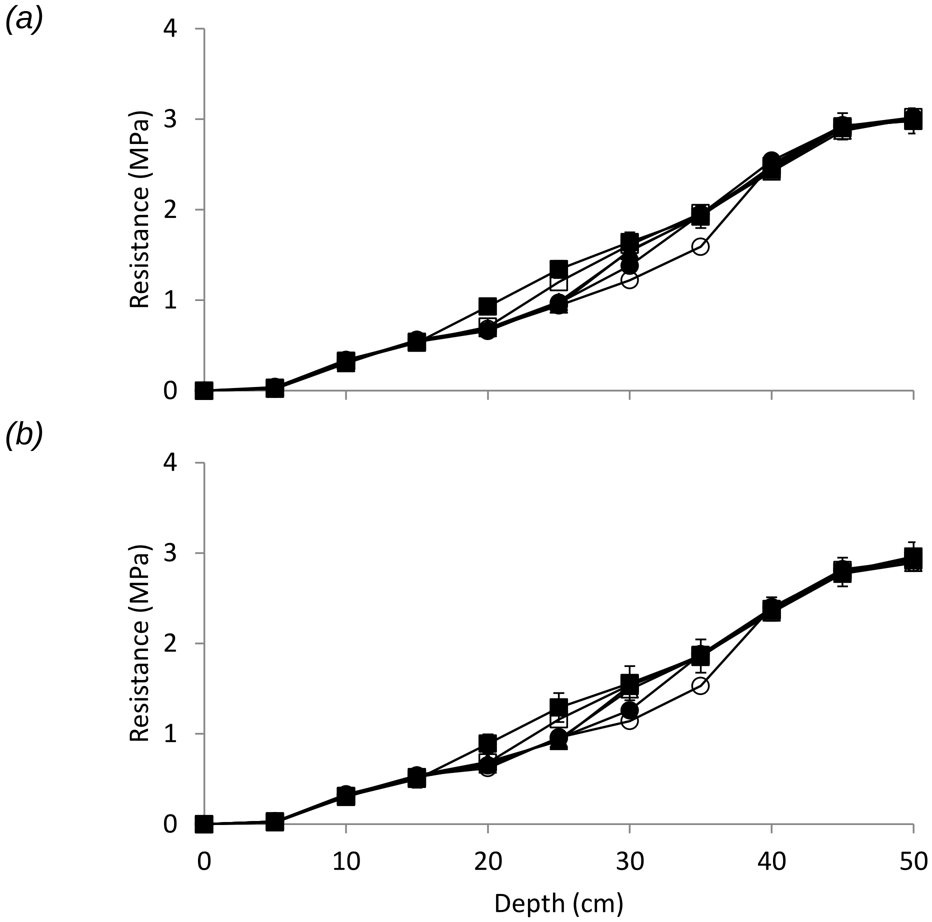
In Expts 2013-3 and 2013-4, there was the same pattern of reduction in resistance with increase in destoning depth in both the light and heavy areas of the field (Figure 31). There was no evidence of compaction caused by cultivating deeper.

Figure 31. 2013: Effect of destoning depth on soil resistance at planting in *(a)* Expt 2013-3 and *(b)* Expt 2013-4. Depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. S.E. bars based on 15 D.F.



In Expts 2013-5 and 2013-6, as destoning depth increased, the average resistance in the top 35 cm decreased but the changes in resistance were small and only significant when comparing the shallowest and deepest destoning depths (Figure 32). There was no evidence of a pan being created at planting by destoning deeper than the commercial depth (26 cm).

Figure 32. **2013: Effect of destoning depth on soil resistance at planting in *(a)* Expt 2013-5 and *(b)* Expt 2013-6. Depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. S.E. bars based on 15 D.F.**



4.2.4.5. Ped size distribution

The general conclusion to the analysis of ped size distribution was that as the clay content of the soils increased, mean ped size and the proportion of peds >6 mm increased. In Expt 2013-7, ped size decreased significantly between planting and harvest but in most other experiments the change in ped size during the season was largely insignificant (Table 28 and Table 29).

There was little effect of destoning depth on either the mean ped size or the proportion of peds >6 mm in diameter within a particular experiment (Table 31 and Table 32). However, there were some interesting findings. In Expt 2013-1, mean ped size increased significantly more between planting and harvest in the two deepest destoning depths than shallower depths (Table 31). In Expt 2013-2, the shallowest destoning depth had the lowest proportion of peds >6 mm at both planting and harvest

(Table 31). In Expt 2013-5, at planting, the two deepest destoning depths had larger peds and more peds >6 mm than shallower depths but there was no effect at harvest or in the heavier soil in the same field (Expt 2013-6). In Expt 2013-19, primary cultivations conducted with the Simba Solo had smaller mean ped size at harvest (5.3 ± 0.42 mm) than ploughing (6.8 mm) or Tillerstar (6.2 mm) treatments.

Table 31. 2013: Effect of destoning depth on mean ped size at planting and harvest in Expts 2013-1 to 2013-7. S.E. based on 15 D.F.

Sample date	Planting							Harvest						
	Destoning depth							Destoning depth						
Expt	1	2	3	4	5	6	S.E.	1	2	3	4	5	6	S.E.
2013-1	6.7	6.8	6.9	6.6	6.4	5.8	0.55	7.5	6.3	6.2	7.3	8.4	8.7	0.96
2013-2	7.9	8.8	7.9	8.4	8.8	9.7	0.57	10.9	10.1	10.1	11.8	12.4	11.7	1.30
2013-3	4.0	4.9	3.9	4.0	4.4	4.4	0.37	4.3	4.4	4.3	3.7	4.0	4.1	0.38
2013-4	5.5	4.6	4.9	4.5	5.0	5.2	0.20	6.6	6.2	6.2	7.1	5.0	5.1	0.58
2013-5	9.0	9.0	8.3	9.3	10.0	10.6	0.45	9.4	11.1	9.4	9.2	10.2	9.6	1.45
2013-6	11.4	11.5	11.6	11.8	11.7	12.9	0.72	9.4	10.1	9.0	10.3	11.1	11.1	1.57
2013-7	11.8	12.7	-	12.9	-	13.4	0.51	9.9	9.6	-	9.2	-	10.4	0.57

Table 32. 2013: Effect of destoning depth on proportion of peds >6 mm at planting and harvest in Expts 2013-1 to 2013-7. S.E. based on 15 D.F.

Sample date	Planting							Harvest						
	Destoning depth							Destoning depth						
Expt	1	2	3	4	5	6	S.E.	1	2	3	4	5	6	S.E.
2013-1	34.0	33.2	33.7	31.3	32.4	30.5	2.12	36.3	29.9	30.0	34.2	39.3	43.5	3.39
2013-2	43.1	48.2	46.3	50.3	50.7	56.2	2.04	48.1	50.8	53.7	57.2	55.9	57.2	2.09
2013-3	21.1	25.5	19.9	20.7	22.3	21.3	2.13	22.2	22.8	22.4	19.4	21.6	21.3	2.34
2013-4	32.1	30.2	33.7	31.9	27.0	28.4	1.96	29.2	26.0	27.4	25.0	27.0	26.9	1.08
2013-5	44.2	44.6	42.9	45.1	51.0	52.3	2.15	47.4	52.0	45.3	44.3	49.7	48.5	4.40
2013-6	59.9	58.8	60.3	61.4	61.0	68.4	3.22	48.1	53.2	48.6	53.0	52.3	54.1	3.75
2013-7	62.6	65.5	-	66.0	-	69.3	1.78	52.7	51.9	-	48.5	-	54.9	3.36

4.2.5. Planting depth and emergence

The intended target commercial planting depth was generally achieved for all depths of destoning in all experiments, even for very shallow destoning (Table 33). The coefficient of variation in planting depth was also not affected by destoning depth, indicating that a consistent depth of soil for accurate planting was achieved, irrespective of destoning depth. Shallow destoning did not lead to variable planting depth as is often reported when it is difficult to achieve adequate soil depth within beds. Despite there often being a large difference in texture between the experiments within the same field or within the experiment itself, the experiments in the heavy soil areas were planted at a similar depth to those in lighter areas but there was a trend for greater variation in planting depth along the rows in heavier compared with light areas of fields.

Table 33. 2013: Effect of destoning depth on planting depth (cm) in Expts 2013-1 to 2013-8

		Destoning depth						
Expt	Target	1 Shallowest	2	3	4 Commercial	5	6 Deepest	S.E. 15 D.F
2013-1	14	13.4	14.1	13.6	14.2	13.8	13.6	0.42
2013-2	14	13.9	13.9	13.5	14.2	13.7	13.4	0.56
2013-3	15	15.4	15.6	15.3	15.6	14.9	15.2	0.22
2013-4	15	15.8	15.9	16.2	15.8	15.4	15.6	0.33
2013-5	17	18.1	17.9	18.0	18.6	18.0	18.0	0.19
2013-6	17	18.2	18.0	18.4	18.2	17.7	17.8	0.38
2013-7	15	14.4	14.1	-	13.8	-	13.9	0.40
2013-8	14	-	13.2	12.5	12.5	-	13.5	0.37

As might be expected from a generally consistent planting depth, the interval from planting to emergence was not affected by destoning depth in all experiments. In Expt 2013-1, 50 % emergence was 41 days after planting for all destoning depths and there were similar numbers of plants emerged in all strips used to measure emergence, irrespective of depth of cultivation or soil type. A similar lack of effects was observed in Expt 2013-2 in the same field but it emerged 49 days after planting, 8 days later than Expt 2013-1, most probably associated with the cloddier soil in the heavier areas of the field. In Expts 2013-3 and 2013-4, there was no effect of soil type or destoning depth on the interval from planting to 50 % emergence (38-39 days). In Expts 2013-5 and 2013-6, the interval from planting to 50 % plant emergence was the same (38-39 days) irrespective of the difference in soil type between experiments and destoner depth. In Expt 2013-7, 50 % emergence was 31-32 days after planting, irrespective of destoning depth.

4.2.6. Tuber yield

4.2.6.1. Cultivation depth experiments

Similar to 2012, increasing destoning depth beyond the commercial depth was generally associated with numerically lower yields, although in individual experiments these were mainly not significantly different. In Expt 2013-1 situated in the sandy area of the field, the deepest destoning (49 cm) resulted in lower yield than shallower depths but the difference was not significant (Table 34). In Expt 2013-2, on the heavy side of the field, there was a trend for yield to decrease with increasing destoning depth below 26 cm but the effect was not significant (Table 34). There was no effect of cultivation depth on number of tubers or tuber [DM] in either experiment but the heavier site had fewer tubers than the light site (Table 34).

Table 34. 2013: Yield, number of tubers >10 mm and tuber [DM] in Expts 2013-1 and 2013-2 (harvested on 23 September)

Expt	Destoner depth (cm)	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
2013-1	1 Shallowest	54.0	347	23.0
	2	52.5	320	22.5
	3	53.4	325	22.5
	4 Commercial	52.0	349	22.3
	5	54.4	352	23.6
	6 Deepest	48.9	386	22.2
	S.E. (15 D.F.)	2.68	31.2	0.46
2013-2	1 Shallowest	48.7	333	22.4
	2	49.1	324	22.8
	3	45.8	313	23.4
	4 Commercial	46.7	315	22.3
	5	45.7	292	23.1
	6 Deepest	43.1	307	23.4
	S.E. (15 D.F.)	2.60	22.2	0.24

In Expt 2013-3, there was a significantly lower yield at the deepest depth of destoning (45 cm) compared with the commercial and shallower depths (Table 35). In the heavier end of the field (Expt 2013-4), yield was numerically greater for all depths shallower than the commercial depth, although the difference was not significant (Table 35). There was no significant effect of cultivation depth on number of tubers or tuber [DM] in either experiment (Table 35).

Table 35. 2013: Yield, number of tubers >10 mm and tuber [DM] in Expts 2013-3 and 2013-4 (harvested on 23 September)

Expt	Destoner depth (cm)	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
2013-3	1 Shallow	48.7	446	24.6
	2	48.0	466	25.7
	3	47.9	435	24.2
	4 Commercial	48.0	435	25.0
	5	44.3	432	24.5
	6 Deep	39.5	395	24.8
	S.E. (15 D.F.)	2.52	26.3	0.51
2013-4	1 Shallow	44.2	478	24.5
	2	45.1	501	25.0
	3	45.0	450	25.1
	4 Commercial	41.5	464	24.6
	5	41.4	429	24.3
	6 Deep	41.3	426	25.5
	S.E. (15 D.F.)	1.53	32.2	0.31

In both Expt 2013-5 and Expt 2013-6, there was a trend for yield to decrease as destoning depth was increased below the commercial depth but it was not statistically significant in either experiment (Table 36). There was no effect of cultivation depth on number of tubers or tuber [DM] in either experiment but the heavier site had fewer tubers and lower tuber [DM] than the light site (Table 36).

Table 36. 2013: Yield, number of tubers >10 mm and tuber [DM] in Expts 2013-5 and 2013-6 (harvested on 12 September)

Expt	Destoner depth (cm)	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
2013-5	1 Shallow	62.3	396	21.9
	2	63.4	374	21.6
	3	63.4	376	21.8
	4 Commercial	64.2	411	21.8
	5	61.2	365	21.9
	6 Deep	60.2	383	21.4
	S.E. (15 D.F.)	2.22	21.0	0.39
2013-6	1 Shallow	57.0	342	20.4
	2	57.6	349	20.2
	3	56.5	334	21.1
	4 Commercial	58.6	330	21.1
	5	54.8	336	20.9
	6 Deep	54.4	351	20.9
	S.E. (15 D.F.)	2.25	19.5	0.42

In Expt 2013-7, yields at the commercial depth of destoning (26 cm) and the deepest depth were numerically lower than at the two shallowest depths, although the yield differences were not significant (Table 37). The number of tubers and [DM] were not affected by destoning depth.

Table 37. 2013: Yield, number of tubers >10 mm and tuber [DM] in Expt 2013-7 (harvested on 10 September)

Destoner depth (cm)	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
1 Shallow	50.0	352	19.1
2	50.2	342	18.7
3 Commercial	47.9	338	18.6
4 Deep	47.7	343	18.7
S.E. (15 D.F.)	1.89	17.6	0.32

In Expt 2013-8, there was no effect of destoning depth on yield, even from cultivating 9 cm shallower than the commercial depth of 35 cm. The number of tubers and tuber [DM] were not affected by destoning depth (Table 38).

Table 38. 2013: Yield, number of tubers >10 mm and tuber [DM] in Expt 2013-8 (harvested on 11 September)

Destoner depth (cm)	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
1 Shallow	74.4	760	17.8
2	72.6	753	17.9
3 Commercial	72.6	777	17.9
4 Deep	72.0	776	18.1
S.E. (15 D.F.)	1.14	23.7	0.24

In Expt 2013-9, there was no effect of destoning depth on yield when harvested on 20 August. Yields at 25, 30 and 35 cm were 46.7, 46.2 and 43.5 (± 1.79) t/ha, respectively. In Expt 2013-10, there was no effect of destoning depth on yield on 4 October. At 25, 35 and 45 cm, yields were 50.2, 54.4 and 52.9 (± 2.67) t/ha, respectively. Similarly, there was not effect of bedforming depth yields at 40, 50 and 60 cm were 53.7, 52.1 and 51.8 (± 2.67) t/ha, respectively.

In Expt 2013-19, there was PCN infection observed in one replicate and the analysis was restricted to three replicate blocks. There was no significant effect of either primary or secondary cultivation machinery or depth of destoning on total or >40 mm yield (Table 39).

Table 39. Expt 2013-19: Total and >40 mm yield (harvested on 1 October)

Primary cultivation	Secondary cultivation	Total yield (t/ha)	>40 mm yield (t/ha)
Plough	25 cm	60.9	51.1
	35 cm	58.6	51.1
Simba	25 cm	62.6	55.8
	35 cm	58.9	52.5
Tillerstar		57.5	50.9
	S.E. (4 D.F.)	1.96	2.75
	S.E. (same primary)	1.69	1.93
Plough		59.7	51.1
Simba		60.8	54.2
Tillerstar		57.5	50.9
	S.E. (4 D.F.)	1.55	1.94
	25 cm	61.7	53.5
	35 cm	58.7	51.8
	S.E. (4 D.F.)	1.39	1.68

4.2.7. Soil mineral nitrogen and crop nitrogen uptake

At each of the six sites, soil mineral N (SMN) was measured on two occasions: around the time of crop emergence and when the plots were harvested in the autumn. When averaged over sampling position and destoning depth, SMN at crop emergence ranged from 69 to 260 kg N/ha at Expt 2013-14 and Expt 2013-18, respectively (Table 40). Destoning depth had no statistically significant effect on the amount of SMN in either the centre of the bed (0-90 cm) or in the centre of the furrow (30-90 cm) in any experiment. At final harvest, average soil mineral N ranged from 14 kg N/ha (Expt 2013-15) to 71 kg N/ha (Expt 2013-18). Depth of destoning had no statistically significant effect on SMN residues remaining in the soil after the crop had been harvested and these results were consistent with those found in similar experiments in 2011 and 2012.

Table 40. 2013: Main effects of destoning depth and sampling position on soil mineral nitrogen (kg N/ha) on two occasions in Expts 2013-13 to 2013-18. All soil samples were taken from plots receiving no N fertilizer

		Destoner depth		Position		
Expt	Mean	Deep	Shallow	Furrow	Bed	S.E.
2013-13						
2 July	80	72	87	61	98	10.6
15 October	56	56	56	58	55	7.9
2013-14						
13 June	69	70	67	63	74	4.8
10 October	41	42	39	34	47	5.5
2013-15						
16 May	101	100	102	78	125	16.9
17 September	15	18	12	15	15	3.5
2013-16						
4 June	91	89	94	59	124	6.9
18 September	61	58	64	54	68	20.3
2013-17						
4 June	121	143	98	62	179	27.4
28 August	41	43	38	46	36	6.5
2013-18						
13 June	260	252	268	124	397	39.1
16 September	71	98	45	63	79	22.7

The effects of nitrogen application rate and destoning depth on tuber FW yield, tuber and total dry matter yield and N uptake are shown in Table 41 and Table 42. The mean yield (> 10 mm) for each site ranged from 38.1 t/ha (Expt 2013-18) to 57.5 t/ha (Expt 2013-17). At four of the six experiments, tuber FW yield was increased when the N application rate was increased from 0 to 200 kg N/ha. However, in Expt 2013-18, increasing the N application rate from 0 to 180 kg N/ha was associated with a yield increase of only 2.8 t/ha and this increase was not statistically significant. In Expt 2013-17, where three N application rates were tested, there was an indication of an over-turning response to N fertilizer but this was not statistically significant and the optimum N application rate for this crop was probably zero. Depth of destoning had no statistically significant effect on total tuber FW yield at any site. Average tuber DM yields varied from 8.5 t/ha (Expt 2013-18) to 13.4 t/ha (Expt 2013-13) and total DM yields ranged from 10.3 t/ha (Expt 2013-14) to 15.9 t/ha (Expt 2013-13). Tuber and total DM yields were significantly increased by N in Expts 2013-13 to 2013-16 but not in Expts 2013-17 and 2013-18. Depth of destoning had no effect on either tuber or total DM production at any site.

The smallest mean tuber N uptake (94 kg N/ha in Expt 2013-15) was about one third of the largest (262 kg N/ha in Expt 2013-13). Total N uptakes ranged from 106 to 295 kg N/ha in Expt 2013-15 and Expt 2013-13, respectively. Tuber and total N uptake was significantly increased by N fertilizer at each site. However, neither tuber nor total N uptake was affected by depth of destoning and this is consistent with observations made in 2011 and 2012. The efficiency with which crops recovered N (defined as the increase in total N uptake as a percentage of N fertilizer) was variable. For example in Expt 2013-18, the efficiency of N uptake was only *c.* 22 % (i.e. an increase in total N uptake of 40 kg N/ha resulting from applying 180 kg N/ha as fertilizer) compared with 47 % in Expt 2013-16 and 52 % in Expt 2013-13.

With the exception of Expt 2013-18, all the experimental sites would be classified as mineral soils within RB209. Since the previous cropping at these sites was also unlikely to leave substantial N residues for the subsequent potato crops, the soils would be classified as Soil N Supply (SNS) Index 0 or 1. In consequence, the five mineral soils would be expected to supply < 80 kg N/ha to the potato crop. With the exception of Expt 2013-15, where the total N uptake of unfertilized crops averaged 79 kg N/ha, the soil N supply was substantially more than this, and in the cases of

Expts 2013-13 and 2013-17, the total N uptake indicated an SNS Index of at least 5. More work is needed to better understand what causes these large differences in SNS in superficially similar soils. This knowledge will assist in improving fertilizer recommendation schemes.

The absence of any effect of destoning depth on N uptake is consistent with depth of cultivation having little consistent effect on soil mineral N when measured at crop emergence. As was noted in 2012, this is probably a consequence of the majority of the soil's organic matter being in the top 25 cm of soil and thus both shallow and deep cultivations were probably exposing similar amounts of organic matter to oxidation and similar conditions for microbial growth leading to the release of similar amounts of SMN. Collectively, data from 2011, 2012 and 2013 suggest that, within the limits of commercial practise, shallower destoning is unlikely to result in less mineralisation of N from the soil organic matter and therefore N fertilizer recommendations will not need be reassessed.

Table 41. 2013: Main effects of nitrogen application rate and depth of destoning on fresh weight and dry weight yields and nitrogen uptake at five locations in 2013

Expt	Mean	N application rate (kg N/ha) 0	200†	Destoning depth Deep	Shallow	S.E. (15 D.F.)
2013-13						
Tuber FW yield (t/ha)	56.0	47.1	65.0	56.8	55.2	1.17
Tuber DW yield (t/ha)	13.4	11.6	15.2	13.6	13.2	0.31
Total DW yield (t/ha)	15.9	13.3	18.5	16.0	15.8	0.30
Tuber N uptake (kg N/ha)	262	226	297	248	275	12.7
Total N uptake (kg N/ha)	295	243	346	280	310	13.2
2013-14						
Tuber FW yield (t/ha)	38.4	32.7	44.2	38.1	38.8	2.97
Tuber DW yield (t/ha)	9.4	8.2	10.6	9.4	9.3	0.64
Total DW yield (t/ha)	10.3	8.9	11.6	10.3	10.2	0.73
Tuber N uptake (kg N/ha)	118	94	142	119	118	10.2
Total N uptake (kg N/ha)	128	101	154	129	127	11.4
2013-15						
Tuber FW yield (t/ha)	46.6	41.4	51.9	47.4	45.9	1.95
Tuber DW yield (t/ha)	11.2	9.7	12.6	11.3	11.0	0.50
Total DW yield (t/ha)	12.4	10.8	13.9	12.6	12.2	0.57
Tuber N uptake (kg N/ha)	94	68	120	94	94	5.1
Total N uptake (kg N/ha)	106	79	134	106	106	5.6
2013-16						
Tuber FW yield (t/ha)	43.4	38.4	48.5	44.0	42.9	0.66
Tuber DW yield (t/ha)	10.5	9.0	12.0	10.7	10.4	0.14
Total DW yield (t/ha)	11.9	10.1	13.7	12.1	11.7	0.17
Tuber N uptake (kg N/ha)	136	95	176	138	133	3.7
Total N uptake (kg N/ha)	156	109	202	159	153	4.2
2013-18						
Tuber FW yield (t/ha)	38.1	36.7	39.5	37.2	39.0	1.48
Tuber DW yield (t/ha)	8.5	8.5	8.6	8.3	8.7	0.30
Total DW yield (t/ha)	12.4	12.2	12.7	12.4	12.5	0.53
Tuber N uptake (kg N/ha)	126	118	134	124	128	6.2
Total N uptake (kg N/ha)	205	185	225	204	206	11.2

†180 kg N/ha in Expt 2013-18

Table 42. 2013: Main effects of nitrogen application rate and depth of destoning in Expt 2013-17

		N application rate (kg N/ha)			Destoning depth			S.E. (16 D.F)
	Mean	0	100	200	Deep	Medium	Shallow	
Tuber FW yield (t/ha)	57.5	55.2	59.5	57.8	60.2	55.2	57.1	2.25
Tuber DW yield (t/ha)	13.3	13.1	13.8	13.1	14.2	12.7	13.1	0.55
Total DW yield (t/ha)	15.8	15.1	16.3	16.1	16.8	15.2	15.5	0.61
Tuber N uptake (kg N/ha)	196	171	197	221	214	181	194	12.9
Total N uptake (kg N/ha)	243	204	245	281	259	228	242	14.2

4.2.8. Tuber quality

Assessments of tuber skin quality (common scab, greening and external cracking) were made on all destoning depth experiments targeted for packing (Expts 2013-1, 2013-2, 2013-5, 2013-6, 2013-7, 2013-8 and 2013-12). There was no effect of destoning depth on tuber greening or external cracking (data not shown) and no effect on common scab in any experiment examined (Table 43). These findings support the observations made in 2011-2012 that destoning depth has little effect on the severity of common scab and greening despite the wide range of soils studied in the project.

Table 43. 2013: Effect of destoning depth on incidence and severity (% surface area, SA) of common scab at final harvest in Expts 2013-1, 2013-2, 2013-5, 2013-6, 2013-7, 2013-8 and 2013-12

Expt	Destoner depth	Incidence < 5 % SA (%)	Severity (% SA)
2013-1	Shallow	99.5	0.91
	Commercial	96.0	1.44
	Deep	97.0	1.42
2013-2	Shallow	97.0	1.14
	Commercial	96.0	1.29
	Deep	99.5	0.70
2013-5	Shallow	97.0	1.39
	Commercial	97.4	1.11
	Deep	93.0	1.69
2013-6	Shallow	98.0	1.00
	Commercial	96.5	1.49
	Deep	98.0	0.88
2013-7	Shallow	100.0	0.55
	Commercial	100.0	0.53
	Deep	100.0	0.58
2013-8	Shallow	100.0	0.60
	Commercial	100.0	0.55
	Deep	100.0	0.55
2013-12	Shallow	99.5	0.59
	Commercial	98.7	0.64

4.2.9. Bruising during commercial harvesting

At two of the sites selected for the work due to their high stone content (Expts 2013-9 and 2013-15), there was a significant increase in the incidence of blackspot bruising and the number of bruises per tuber when destoning shallower than the commercial depth of 35 cm (Table 44). In Expt 2013-9, there were on average 430 kg/ha of stones and clods collected on the picking table in the 25 cm destoning treatment, 287 kg/ha in the 30 cm and 109 (± 31.0) kg/ha in the 35 cm, indicating that stones were removed by deeper destoning but allowing for a 28 cm depth of harvesting, these are tiny fractions (< 0.01 %) of the soil and tubers lifted by the harvester. There were no significant differences in bruising between shallow (25 cm) and commercial-depth (35 cm) destoning in the other experiments. The incidence of sliced tubers (assumed to be from insufficient depth rather than vertical intake disc), was almost zero and unrelated to destoning depth. The overall body of data from 2012 and 2013 shows that it is possible to harvest from beds as shallow as 25 cm but clearly there are cases where bruising can be worse than from deeper destoning.

Table 44. 2013: Effect of destoning depth on blackspot bruising incidence in Expts 2013-9, 2013-11, 2013-12, 2013-15 and 2013-17

	Destoner depth (cm)				
Expt	25	30	35	45	S.E.
2013-9	19.2	19.2	14.0	-	1.23
2013-11	5.7	-	8.3	8.3	1.59
2013-12	7.3	-	2.0	0	2.01
2013-15	12.2	-	8.5	-	0.44
2013-17	15.9	-	12.4	13.1	0.76
Mean	12.0	-	9.0	-	

4.3. 2014

4.3.1. Actual depths of destoning

As in the 2012 and 2013 results, throughout the rest of this part of the report, the destoner depths will be referred to as depths 1-6 and by reference to Table 45, the true depth of bed can be determined. There were few differences between intended and actual depth of destoning (Table 45).

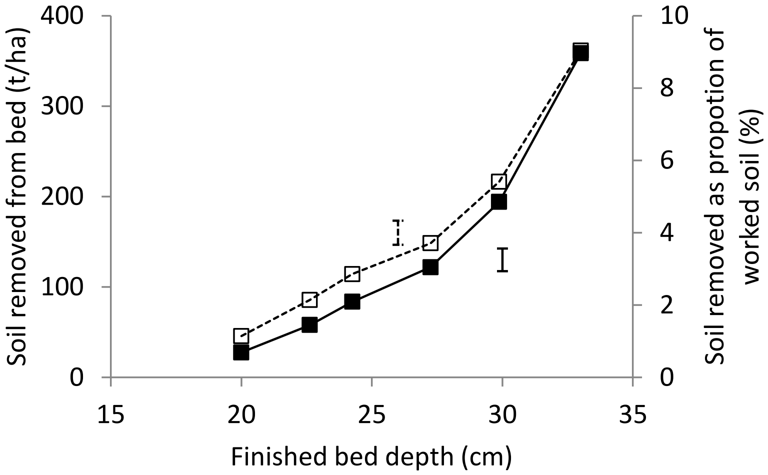
Table 45. 2014: Intended and actual achieved depth (cm) of destoning in Expts 2014-1 to 2014-17. Expt 2014-4 is not listed as depths were continuously variable (28-34 cm), Expt 2014-9 was not destoned and Expt 2014-14 was a fixed depth of 35 cm

		Depth					
Expt	Intended (I) vs Actual (A)	1 Shallowest	2	3	4 Commercial	5	6 Deepest
2014-1	I	25	29	33	37	43	49
	A	26	29	34	37	44	50
2014-2	I	25	28	31	34	39	44
	A	24	27	30	34	38	42
2014-3	I	22	24	26	28	30	33
	A	20	23	24	27	30	33
2014-5	I	25	30	-	35	-	-
	A	25	29	-	35	-	-
2014-6	I	25	-	-	30	35	-
	A	25	-	-	29	34	-
2014-7	I	25	-	-	30	35	-
	A	25	-	-	29	35	-
2014-8	I	25	-	-	30	-	-
	A	24	-	-	29	-	-
2014-10	I	25	-	-	30	-	35
	A	25	-	-	30	-	35
2014-11	I	25	-	-	31	-	39
	A	26	-	-	31	-	38
2014-12	I	25	-	-	35	-	45
	A	28	-	-	37	-	48
2014-13	I	24	28	-	31	-	-
	A	26	28	-	33	-	-
2014-15	I	25	-	-	31	-	35
	A	25	-	-	30	-	35
2014-16	I	25	-	-	32	-	35
	A	25	-	-	30	-	35
2014-17	I	25	30	-	35	-	-
	A	25	31	-	36	-	-

4.3.2. Soil removed from bed during destoning

In Expt 2014-3, the weight of soil removed from the bed and deposited into the adjacent wheeling increased progressively with share depth but there was marked increase in the amount removed as the share depth worked below 30 cm (Figure 33). At the commercial depth, only *c*. 100 t/ha was sieved into the furrow.

Figure 33. 2014: Quantity of soil removed from bed (solid line and symbols) and proportion of soil transferred to furrow (dashed line and open symbols) during destoning in Expt 2014-3. S.E. bars based on 15 D.F.



4.3.3. Rate of work and fuel consumption

The spot forward speeds and rates of work of the different destoner depth treatments are shown in Table 46 and Table 47 respectively, and the fuel consumption in Table 48. Rate of work decreased with depth but there was a very large difference in the rates at different depths between sites. For example, in Expt 2014-5 which was destoned with machines with very fine-pitch (28 mm) webs, there was a 58 % improvement in work rate when reducing destoning depth from 35 cm to 25 cm. By contrast, in Expt 2014-17, differences in forward speed were small (*c*. 3 %) across the range of depths used. The overall mean across all experiments was a 22 % improvement in speed and work rate when destoning at 25 cm compared with 35 cm (Table 46 and Table 47). The heavier soils were not always cultivated slower (e.g. Expt 2014-2 *c.f.* Expt 2014-3) as the commercial depth was generally shallower in fields with > 25 % clay content. Fuel consumption increased with depth, being 13-38 % (mean 25 %) greater at the commercial depth than the shallowest (Table 48). Again, cultivation of the heaviest soil (Expt 2014-3), consumed less fuel than lighter sites as the commercial destoning depth was appreciably shallower. In Expt 2014-4, the speed of variable depth destoning ranged from 2.0-2.6 km/h (mean 2.38 km/h) and fuel consumption ranged from 18.5 to 26.9 l/ha (mean 22.5 l/ha, Table 46 and Table 48). The commercial depth averages for speed and fuel consumption were 2.10 km/h and 32.0 l/ha, respectively. In Expt 2014-5, the web machine was significantly slower (2.18 ± 0.176 km/h) than the narrow star machine (2.93 km/h) and wide star machine (3.38 km/h, Table 46 and Table 48).

Table 46. 2014: Spot forward speeds (km/h) of destoner treatments

	Depth of destoning						
Expt	1 Shallowest	2	3	4 Commercial	5	6 Deepest	S.E.
2014-1	2.70	2.35	2.23	2.05	1.70	1.49	0.086
2014-2	1.23	1.13	1.10	1.08	1.06	0.91	0.045
2014-3	4.03	3.35	3.08	3.05	1.90	1.43	0.177
2014-5†	3.57	2.67	-	2.26	-	-	0.176
2014-6‡	2.45	-	-	1.87	1.43	-	0.079
2014-7‡	2.57	-	-	2.04	1.74	-	0.057
2014-10	2.83	-	-	2.59	-	2.56	0.063
2014-11	2.71	-	-	2.13	-	1.81	0.150
2014-12	2.89	-	-	2.38	-	1.83	0.092
2014-13	1.95	1.93	-	1.88	-	-	0.033
2014-15	4.92	-	-	4.30	-	3.11	0.173
2014-16	5.88	-	-	5.11	-	4.04	0.131
2014-17	3.54	3.48	-	3.43	-	-	0.029

†Mean of three machine types

‡Conventional destoner only

Table 47. 2014: Spot rates of work (ha/h) of destoner treatments

	Depth of destoning						
Expt	1 Shallowest	2	3	4 Commercial	5	6 Deepest	S.E.
2014-1	0.52	0.46	0.43	0.40	0.33	0.29	0.016
2014-2	0.24	0.22	0.21	0.20	0.20	0.18	0.009
2014-3	0.73	0.61	0.56	0.55	0.35	0.26	0.032
2014-5†	0.65	0.49	-	0.41	-	-	0.032
2014-6‡	0.45	-	-	0.35	0.27	-	0.016
2014-7‡	0.47	-	-	0.37	0.32	-	0.010
2014-10	0.52	-	-	0.47	-	0.47	0.011
2014-11	0.50	-	-	0.39	-	0.33	0.028
2014-12	0.53	-	-	0.44	-	0.33	0.017
2014-13	0.36	0.35	-	0.34	-	-	0.006
2014-15	0.90	-	-	0.49	-	0.57	0.032
2014-16	1.08	-	-	0.94	-	0.74	0.024
2014-17	0.65	0.64	-	0.63	-	-	0.006

†Mean of three machine types

‡ Conventional destoner only

Table 48. 2014: Fuel consumption (l/ha) of destoner treatments

	Depth of destoning						
Expt	1 Shallowest	2	3	4 Commercial	5	6 Deepest	S.E.
1	22.8	28.3	30.6	34.3	43.0	49.1	1.39
2	31.1	36.5	38.0	39.6	40.5	51.5	1.60
3	11.4	13.1	15.9	18.5	24.7	32.3	1.37
6†	31.8	-	-	38.9	50.3	-	1.71
7†	28.8	-	-	35.8	41.9	-	1.50
10	34.0	-	-	39.0	-	40.6	0.93
11	31.2	-	-	40.9	-	49.4	3.12
12	22.0	-	-	34.7	-	54.5	2.39
13	39.0	43.8	-	50.4	-	-	1.10
15	21.6	-	-	26.1	-	35.3	0.56
16	19.0	-	-	22.9	-	28.3	0.71
17	17.5	22.4	-	26.3	-	-	0.25

†Conventional destoner only

In Expts 2014-6 and 2014-7, the conventional destoner was compared with the Tillerstar. The latter machine is designed to work on soil that has had minimal preparation from the previous crop if the surface is flat and consolidated. Subsoiling to remove compaction may be necessary, but other surface cultivations are not required. Therefore, to compare the fuel usage of the two-bed Tillerstar used in Expts 2014-6 and 2014-7, the combined fuel usage of the destoning system (two passes of Sumo Trio cultivation, bedforming and single-bed destoning) were compared with the total fuel use of the one-pass Tillerstar system. The Tillerstar cultivated two beds per pass, whilst the destoner was limited to a single bed. Not surprisingly, since the forward speeds of the two machines operating at the same depth were similar, the rates of work were roughly twice as fast with the Tillerstar as the destoner system in both Expt 2014-6 and Expt 2014-7. In reality, the fair judge in terms of working width and rate of work would be to compare the two-bed Tillerstar system with a system operating two single-bed conventional destoners.

In Expt 2014-6, the rate of destoning at 30 and 35 cm was slower with the Tillerstar than the twin destoner system and the rate of work decreased as depth increased, being twice as slow at 35 cm as at 25 cm (Table 49). The Tillerstar consumed 2.3 times as much fuel during destoning at 25 cm as conventional destoner and 2.6 times at 35 cm depth. The total fuel consumed in producing beds for planting was greater for the Tillerstar than destoner system: 11 % greater at 25 cm and 50 % at 35 cm (Table 49).

Table 49. 2014: Rate of work (ha/h) and fuel consumption (l/ha) during destoning in Expt 2014-6. Comparisons based on two, single-bed destoner machine system and two-bed Tillerstar

	Rate		Destoning fuel		Total fuel	
Depth	Destoner	Tillerstar	Destoner	Tillerstar	Destoner	Tillerstar
1	0.90	0.88	31.3	72.1	81.9	91.2
4	0.70	0.63	38.9	93.7	89.5	112.8
6	0.53	0.43	50.3	131.8	100.9	150.9
S.E. (20 D.F.)	0.029		2.76		2.76	
S.E. (same machine, 5 D.F.)	0.032		2.59		2.59	

However, working in the lighter soil in Expt 2014-7, both systems worked at similar rates during destoning but rates decreased as depth increased, being 35 % slower at 35 cm than at 25 cm (Table 50). The Tillerstar consumed more than twice as much fuel during destoning as the conventional destoner, particularly at 35 cm depth. The total fuel usage was similar for the Tillerstar and the destoner system at shallow and commercial depths but the Tillerstar system consumed much more fuel at 35 cm than the destoner system (Table 50).

Table 50. 2014: Rate of work (ha/h) and fuel consumption (l/ha) during destoning in Expt 2014-7. Comparisons based on two, single-bed destoner machine system and two-bed Tillerstar

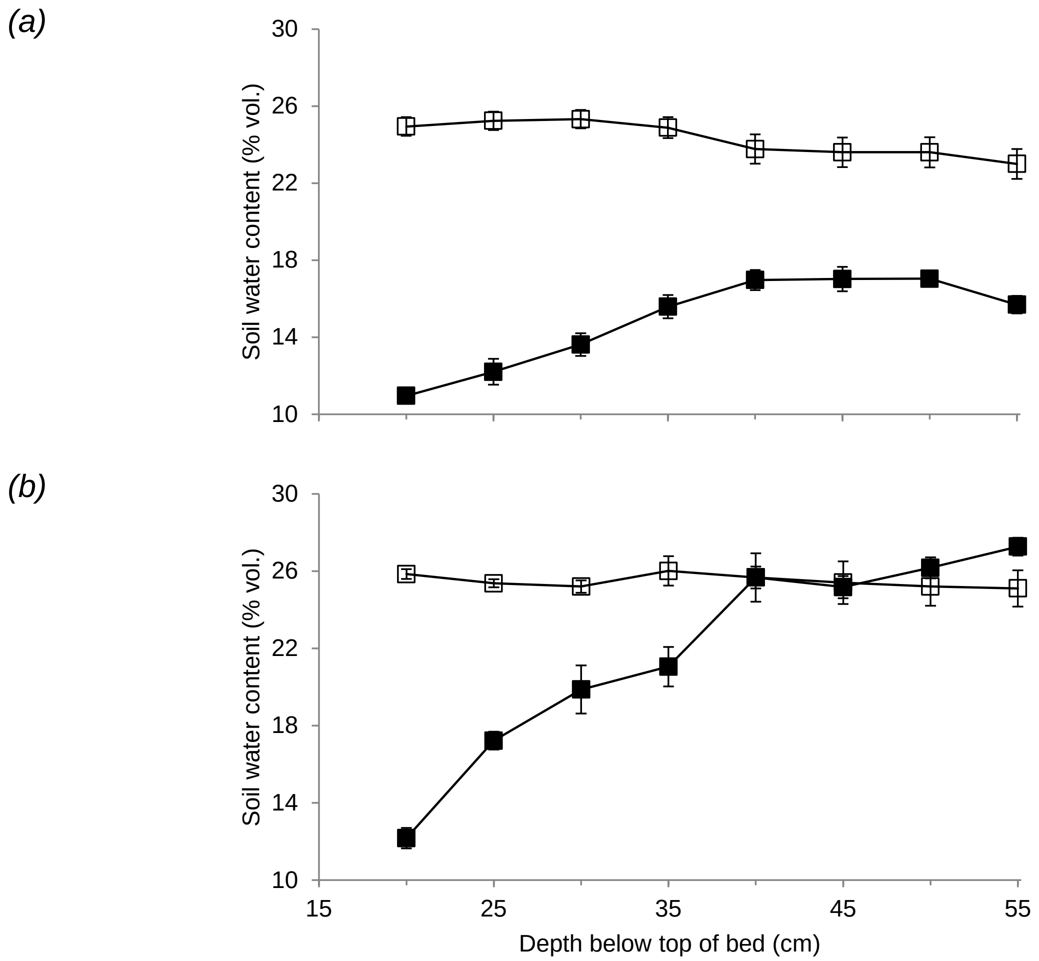
	Rate		Destoning fuel		Total fuel	
Depth	Destoner	Tillerstar	Destoner	Tillerstar	Destoner	Tillerstar
1	0.94	0.92	28.8	57.1	79.4	76.2
4	0.75	0.75	35.8	70.6	86.4	89.7
6	0.64	0.56	41.9	93.2	92.5	112.3
S.E. (20 D.F.)	0.023		1.48		1.48	
S.E. (same machine, 5 D.F.)	0.020		1.50		1.50	

4.3.4. Soil measurements

4.3.4.1. Soil water content and plastic limit at cultivation

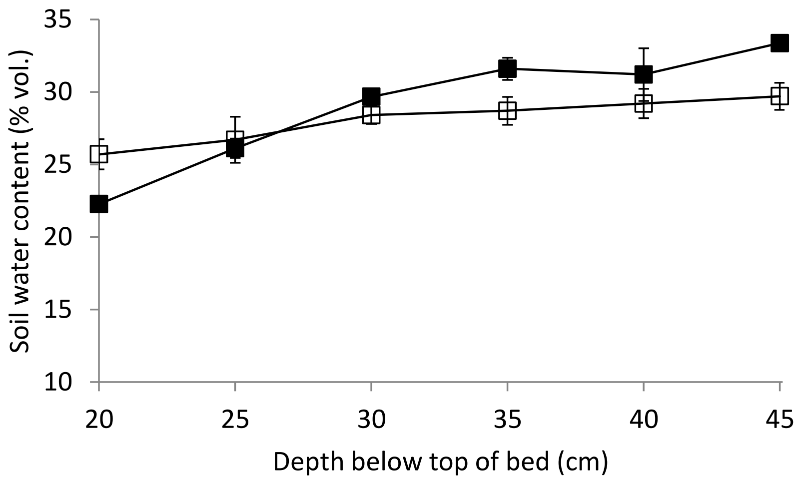
In Expt 2014-1, the soil water content in the bed prior to destoning increased from 11 % (vol.) close to the surface of the bed to a maximum of 17 % at 40-50 cm (Figure 34*a*). The PL was relatively constant with depth but the critical depth for cultivation (where the soil water content line crosses the PL line) was never exceeded as the soil was too sandy and too dry. In the heavy area of the same field (Expt 2014-2), the soil was of similar dryness in the surface of the bed (12 % vol.) as the light area but exceeded 26 % below 40 cm depth (Figure 34*b*). The PL was again relatively constant with depth but the critical depth for cultivation was reached 40 cm below the top of the bed. Destoning deeper than the critical depth is likely to result in plastic deformation i.e. compaction at the share depth.

Figure 34. 2014: Profile of soil water content (■) and lower plastic limit (□) in deep beds immediately prior to destoning. *(a)* Expt 2014-1; *(b)* Expt 2014-2. S.E. bars based on 15 D.F.



In Expt 2014-3, the soil water content in the bed prior to destoning increased from 22 % (vol.) close to the surface of the bed to a maximum of 33 % at 45 cm (Figure 35). The PL was relatively constant below 30 cm depth but was lower in the top 30 cm owing to higher OM and lower bulk density. The critical depth for cultivation (where the PL exceeded the soil water content) lay somewhere between 25 and 30 cm from the top of the bed (Figure 35), which corresponded with destoner depth '3' (26 cm finished bed depth).

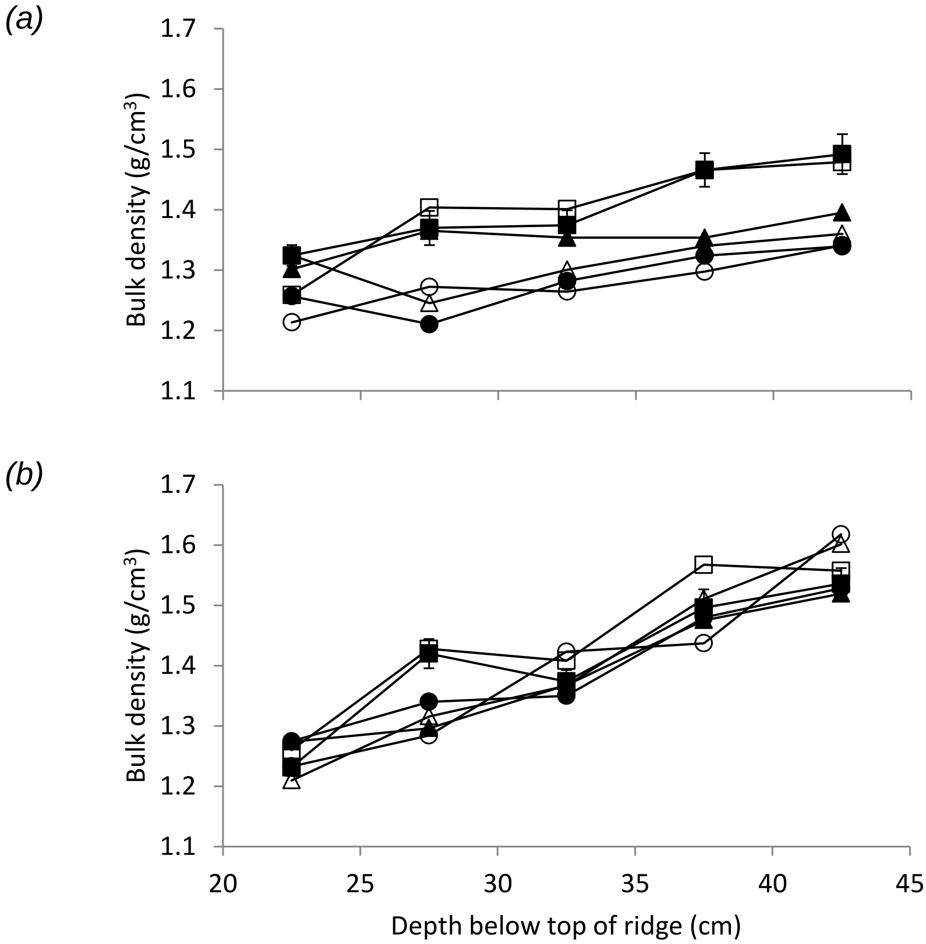
Figure 35. 2014: Profile of soil water content (■) and lower plastic limit (□) in deep beds immediately prior to destoning in Expt 2014-3. S.E. bars based on 15 D.F.



4.3.4.2. Bulk density

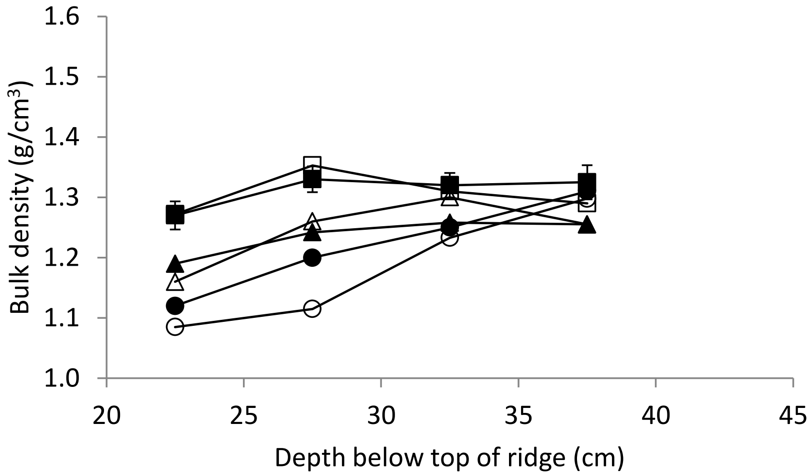
In Expt 2014-1, destoning deeper than 34 cm resulted in lower soil bulk densities below 30 cm than destoning shallower (Figure 36*a*) but there was no apparent decrease in density when destoning deeper than the commercial depth. In Expt 2014-2, there was no significant effect of destoning depth on bulk density except that the two shallowest destoning depths had significantly higher bulk density between 25 and 30 cm than deeper destoning depths (Figure 36*b*). Soil density below 35 cm depth was generally higher in the heavy area (Expt 2014-2) than the light area (Expt 2014-1; Figure 36).

Figure 36. 2014: Effect of destoning depth on soil bulk density in *(a)* Expt 2014-1 and *(b)* Expt 2014-2. Depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. S.E. bars based on 15 D.F.



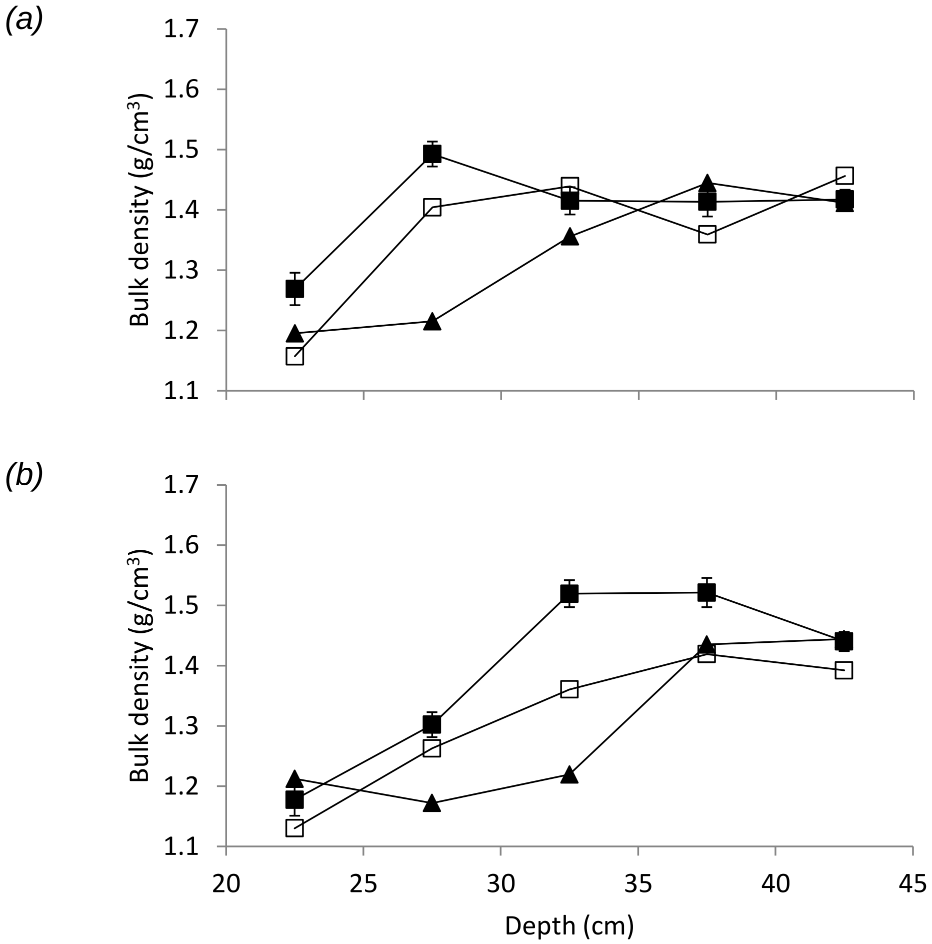
In Expt 2014-3, in general, between 20 and 35 cm below the top of the ridge, as destoning became deeper the bulk density decreased (Figure 37). This created a large range in density (1.12-1.35 g/cm^3) between the shallowest and deepest cultivation treatments in a zone where roots would be expected to proliferate extensively.

Figure 37. 2014: Effect of destoning depth on soil bulk density in Expt 2014-3. Depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. S.E. bars based on 15 D.F.



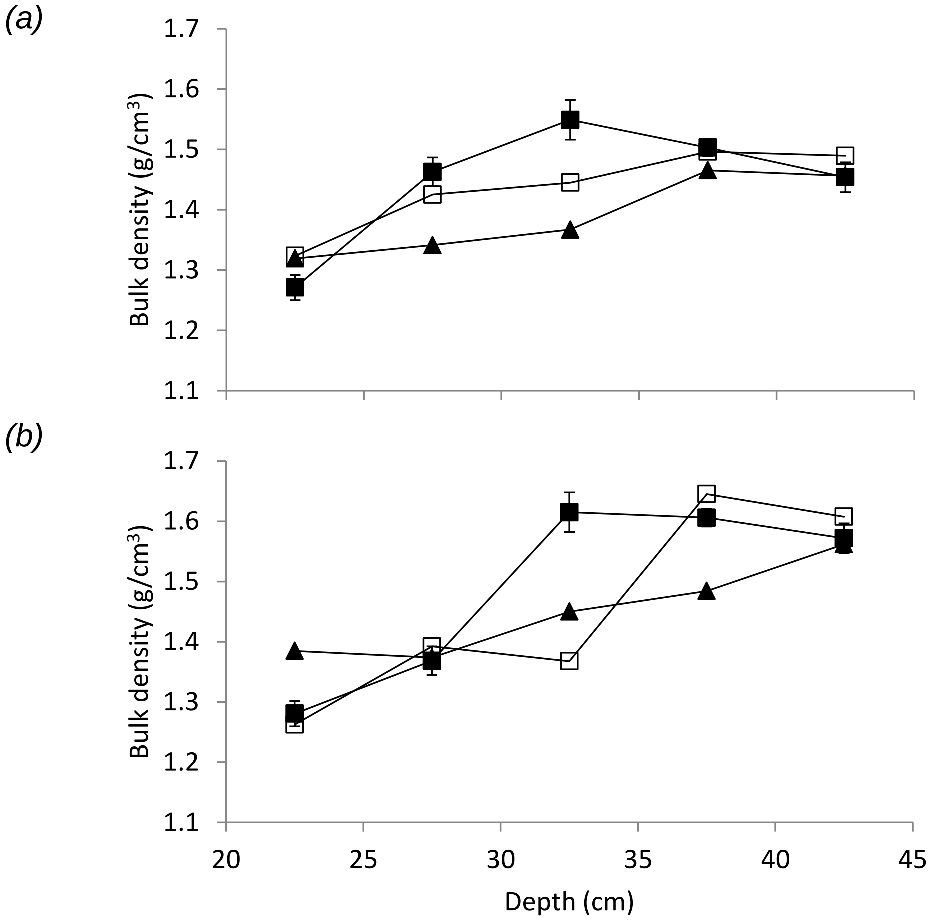
In Expt 2014-6, there was no effect of destoning depth or machine on bulk density in the shallowest (20-25 cm) horizon (Figure 38). In the 25-30 cm horizon, deep (35 cm) destoning resulted in lower density than shallower destoning and the Tillerstar produced lower density than the conventional destoner. When working deeper with the Tillerstar, density decreased in the 30-35 cm zone below the ridge apex but there was no effect in this zone when changing depth with the destoner. In the deepest horizons below 35 cm, machine and depth had no effect on bulk density (Figure 38).

Figure 38. 2014: Effect of machine and destoning depth on soil bulk density in Expt 2014-6. *(a)* Destoner; *(b)* Tillerstar. Depth 1, ■; 4, □; 5, ▲. S.E. bars based on 15 D.F.



In Expt 2014-7, there was no effect of machine or depth on bulk density in the 20-25 and 25-30 cm horizons (Figure 39). In the next horizon (30-35 cm), the shallowest destoning treatment resulted in higher density than deeper destoning, irrespective of machine (Figure 39). In the 35-40 cm horizon, deep (35 cm) destoning reduced the density compared with shallow (25 cm), whilst in the deepest horizon, use of the Tillerstar resulted in higher densities than the conventional destoner (Figure 39).

Figure 39. 2014: Effect of machine and destoning depth on soil bulk density in Expt 2014-7. *(a)* Destoner; *(b)* Tillerstar. Depth 1, ■; 4, □; 5, ▲. S.E. bars based on 15 D.F.

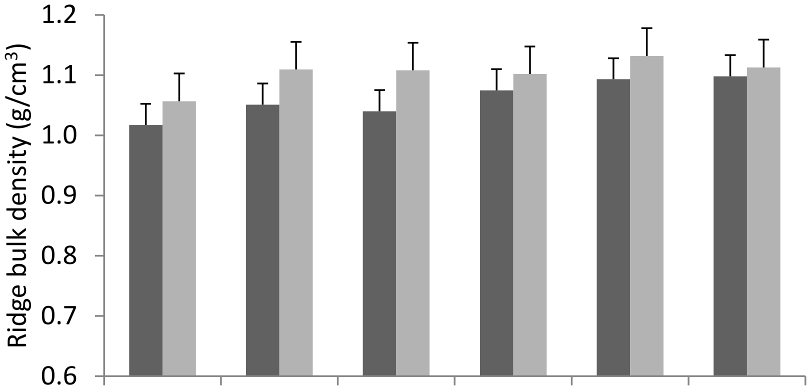


4.3.4.3. Ridge bulk density

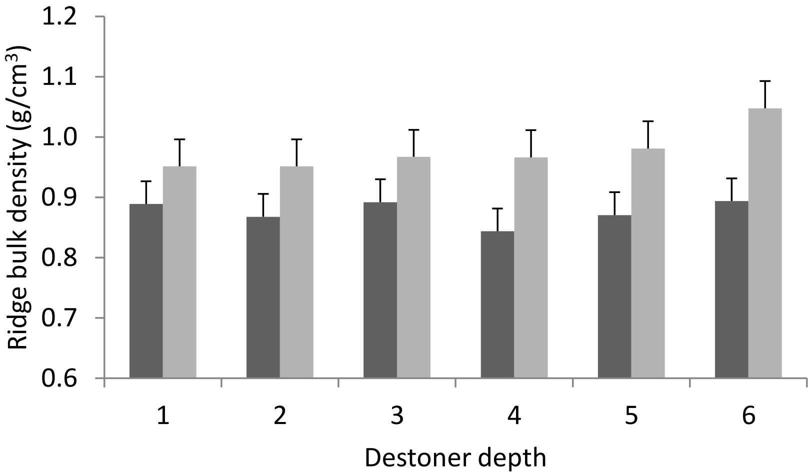
Ridge bulk density was greater in the sandy loam (Expt 2014-1) than the sandy clay loam (Expt 2014-2) soil at both planting and harvest (Figure 40). In both experiments, there was no significant effect of destoning depth on ridge density at either sampling time. Ridge density increased over time in both experiments but the increase was greater in Expt 2014-2 (0.05 g/cm^3) than in Expt 2014-1 (0.10 g/cm^3). In the heavier and cloddier experiment (Expt 2014-2), there was a trend for deeper destoning to result in a greater increase in bulk density between planting and harvest but the differences were not significant (Figure 40*b*)

Figure 40. 2014: Effect of destoning depth on ridge bulk density in *(a)* Expt 2014-1 and *(b)* Expt 2014-2. Planting, ■; Harvest, ■. S.E. bars based on 15 D.F.

(a)

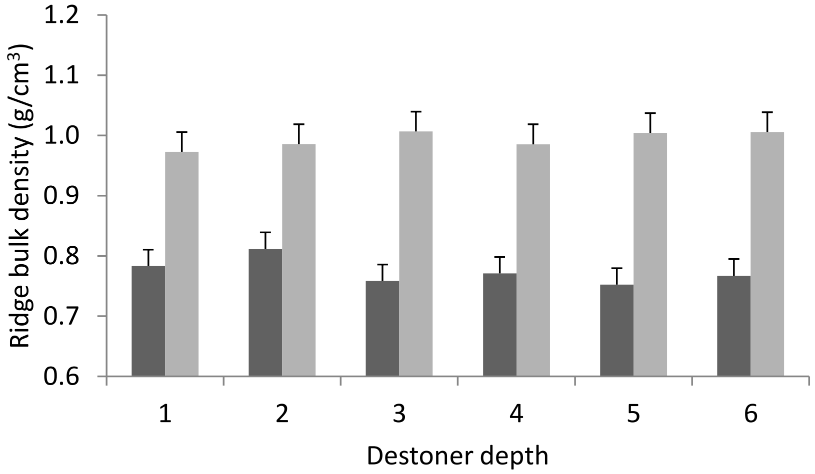


(b)



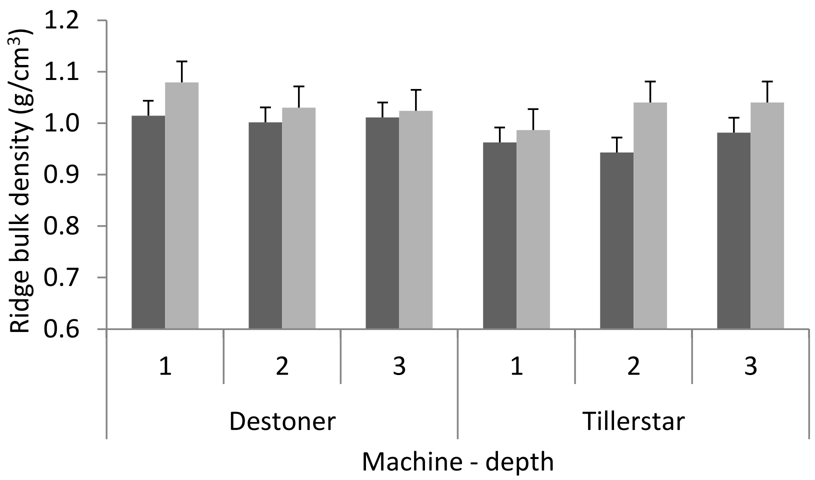
In Expt 2014-3, there was no effect of destoning depth on ridge density at either planting or harvest (Figure 41) but there was a very large increase over time (0.22 g/cm^3 or 29 %) across all cultivation depths.

Figure 41. 2014: Effect of destoning depth on ridge bulk density in Expt 2014-3. Planting, ■; Harvest, ■. S.E. bars based on 15 D.F.



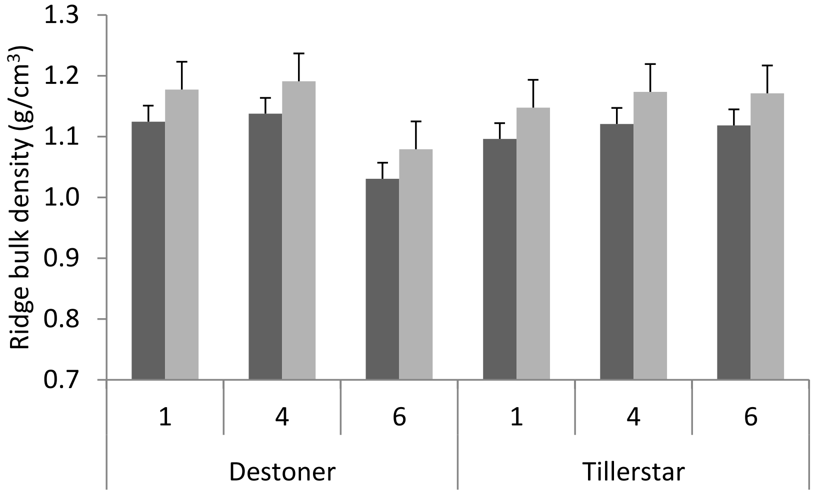
In Expt 2014-6, there was no significant effect of machine or destoning depth on ridge density but there was a trend for the Tillerstar to have lower ridge densities than the conventional destoner immediately following cultivation (Figure 42). Ridge density increased between planting and harvest but only by a small amount (Figure 42).

Figure 42. 2014: Effect of machine and destoning depth on ridge bulk density in Expt 2014-6. Planting, ■; Harvest, ■. S.E. bars based on 12 D.F.



In Expt 2014-7, ridge density was high but there was no effect of either machine or destoning depth on ridge density (Figure 43). Ridge density increased by *c*. 0.05 g/cm^3 during the season, irrespective of machine or depth.

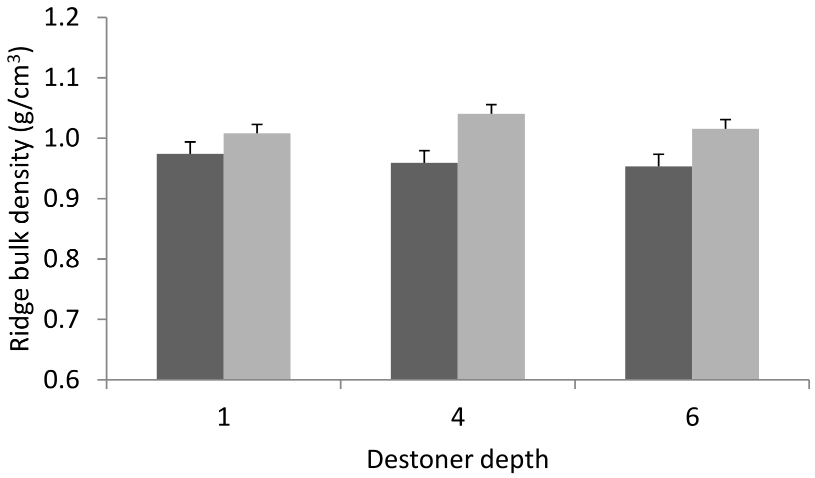
Figure 43. 2014: Effect of machine and destoning depth on ridge bulk density in Expt 2014-7. Planting, ■; Harvest, ■. S.E. bars based on 12 D.F.



At the heavy clay organic site (Expt 2014-8), ridge density was very low owing to the peat content and the large clods. Despite bedtilling and destoning treatments designed to alter aggregate size distribution, there was no effect of cultivator machine on ridge density at harvest (0.63 ± 0.017 g/cm^3).

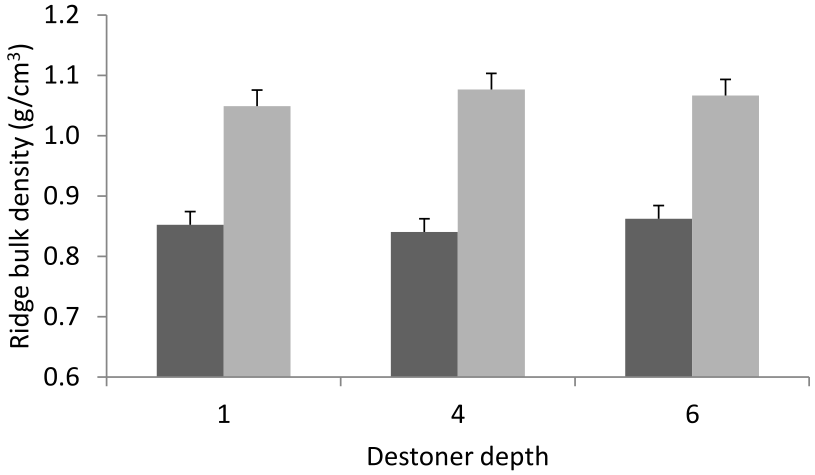
In Expt 2014-10, ridge densities were low and increased slightly more during the season for the two deepest cultivation depths than for the shallowest but there was no effect of destoning depth at either sampling time (Figure 44).

Figure 44. 2014: Effect of destoning depth on ridge bulk density in Expt 2014-10. Planting, ■; Harvest, ■. Mean of both N rates. S.E. bars based on 15 D.F.



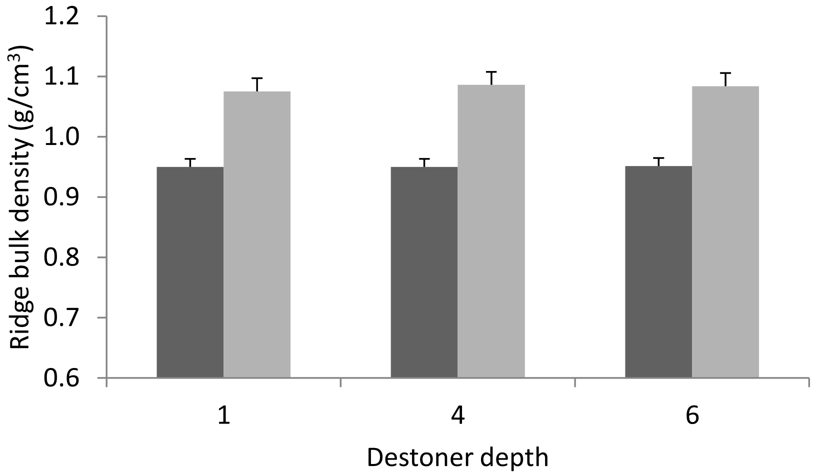
In Expt 2014-11, ridge densities were low at planting and increased significantly by *c*. 0.21 g/cm^3 across all destoner treatments during the season (Figure 45). There was no effect of destoning depth on ridge density at planting or harvest or the change in density during the season.

Figure 45. 2014: Effect of destoning depth on ridge bulk density in Expt 2014-10. Planting, ■; Harvest, ■. Mean of both N rates. S.E. bars based on 15 D.F.



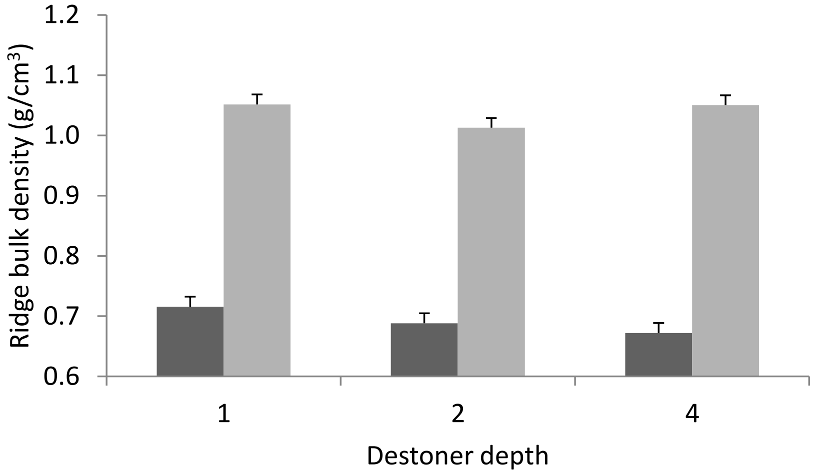
In Expt 2014-12, there was no effect of destoning depth on ridge density at the beginning or end of the season and ridge density increased by *c*. 0.13 g/cm^3 across all destoning depth treatments from planting to harvest (Figure 46).

Figure 46. 2014: Effect of destoning depth on ridge bulk density in Expt 2014-12. Planting, ■; Harvest, ■. Mean of both N rates. S.E. bars based on 15 D.F.



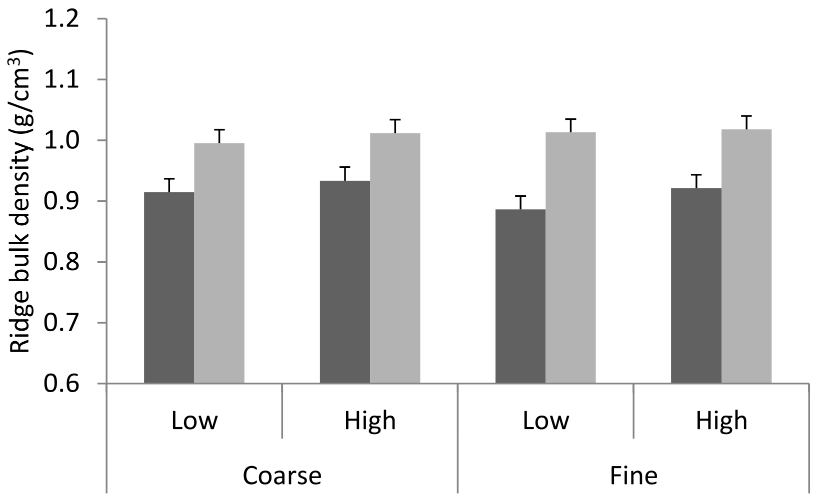
In Expt 2014-13, there was no effect of destoning depth on ridge density at the beginning or end of the season and there was a similar, very large increase (*c*. 0.35 g/cm^3) in ridge density from planting to harvest across all destoner depths (Figure 47).

Figure 47. **2014: Effect of destoning depth on ridge bulk density in Expt 2014-13. Planting, ■; Harvest, ■. Mean of both N rates. S.E. bars based on 15 D.F.**



In Expt 2014-14, there was no effect of bed cloddiness, hood pressure or ridge profile on ridge density at the beginning or end of season and there was a similar, moderate increase (0.10 g/cm^3) in ridge density from planting to harvest across all treatments (Figure 48).

Figure 48. **2014: Effect of bed cloddiness, and ridge pressure on ridge bulk density in Expt 2014-14. Planting, ■; Harvest, ■. Mean of both ridge profiles. S.E. bars based on 14 D.F.**

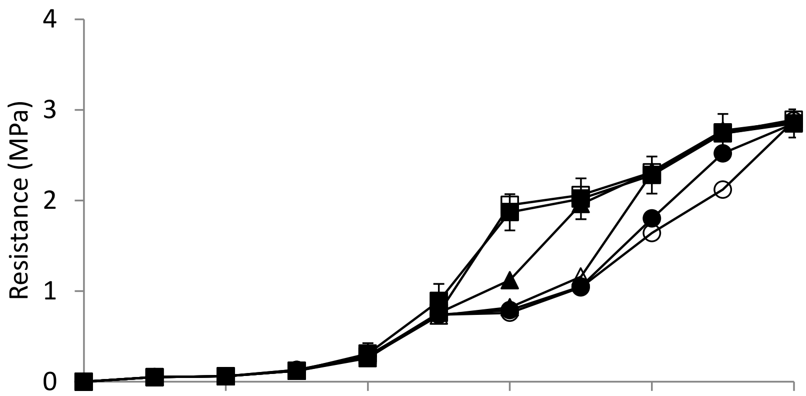


4.3.4.4. Penetration resistance

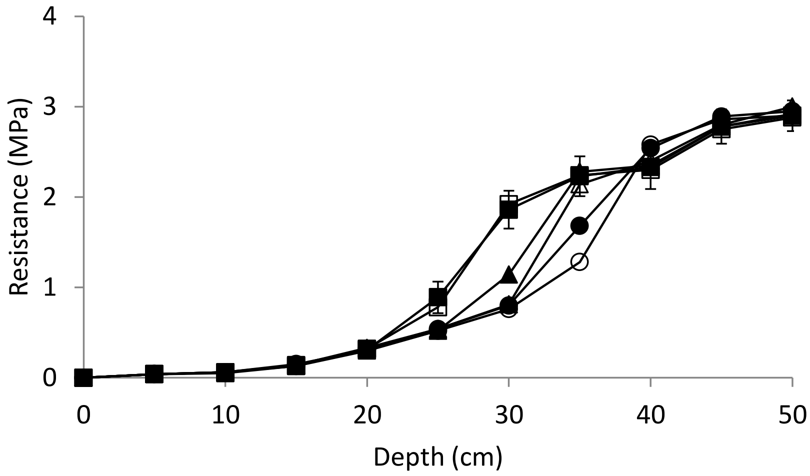
In Expt 2014-1, resistances were low throughout the profile but the two shallowest depths of destoning had significantly greater soil resistance between 25 and 35 cm than the three deepest depths (Figure 49*a*). As soil was worked progressively deeper, the soil resistance decreased deeper in the profile. There was no sign of a compaction pan created by destoning too deeply. In Expt 2014-2, the soil was not loosened to such a great extent by deep destoning as in Expt 2014-1 (Figure 49*b*), most probably as working soil beyond the PL depth resulted in large quantities of soil being deposited in the wheeling with no increase in bed depth.

Figure 49. 2014: Effect of destoning depth on soil resistance at planting in *(a)* Expt 2014-1 and *(b)* Expt 2014-2. Depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. S.E. bars based on 15 D.F.

(a)

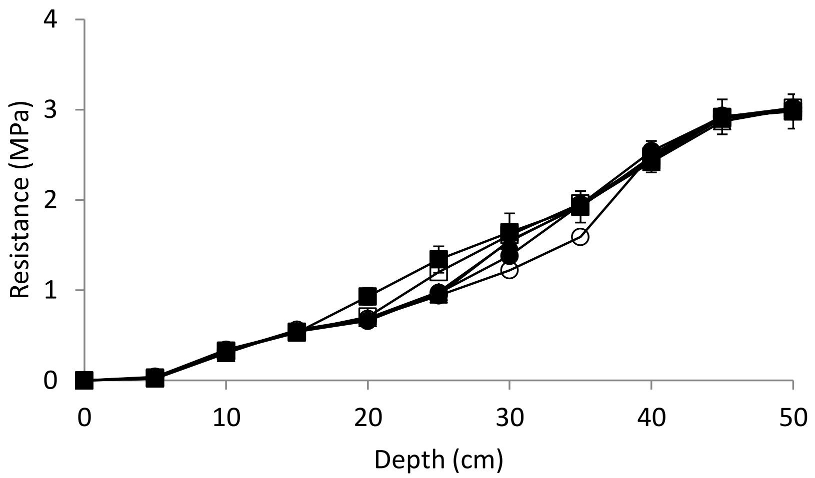


(b)



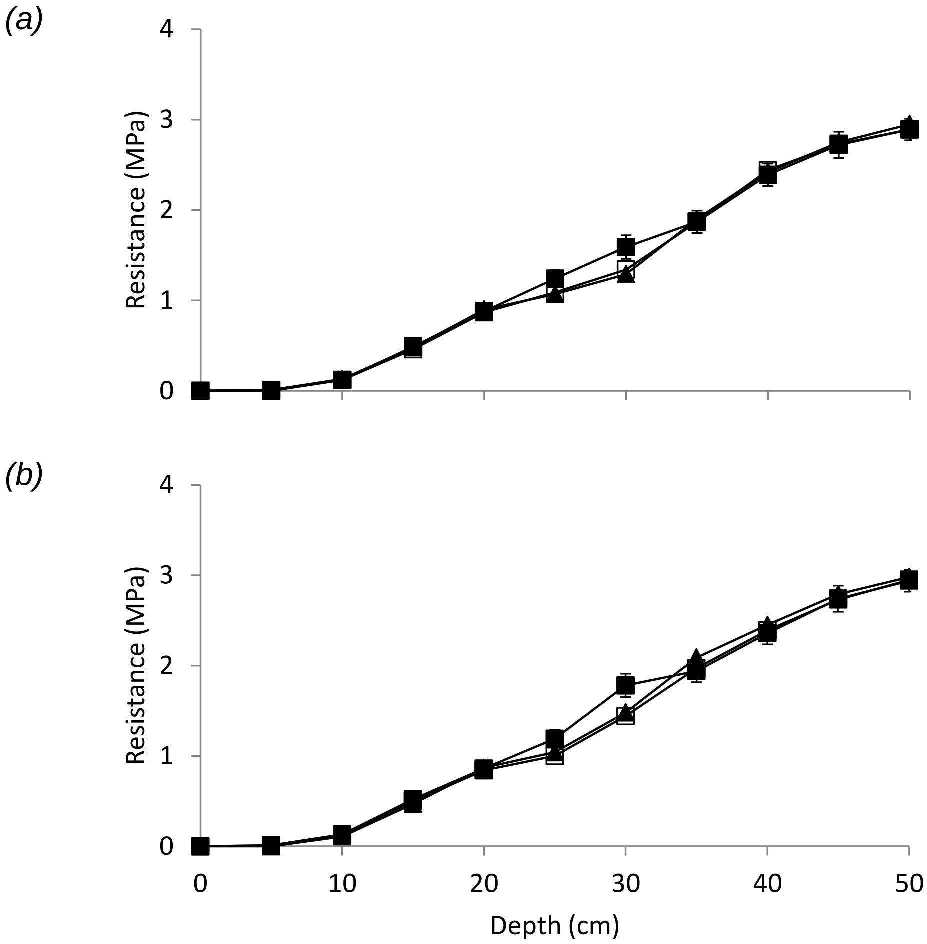
In Expt 2014-3, destoning depth had little effect on soil resistance but there was an indication that destoning at the deepest depth resulted in higher soil resistance at 35 cm than when destoning slightly shallower (Figure 50).

Figure 50. 2014: Effect of destoning depth on soil resistance at planting in Expt 2014-3. Depth 1, ■; 2, □; 3, ▲; 4, △; 5, ●; 6, ○. S.E. bars based on 15 D.F.



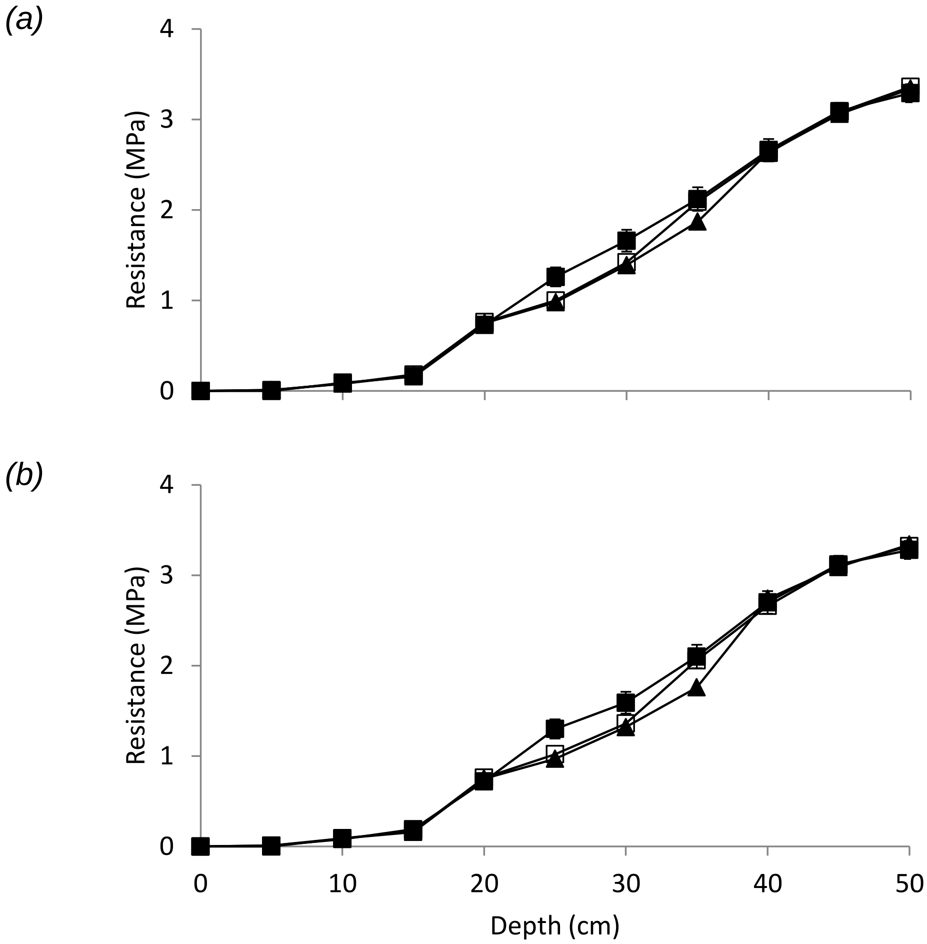
In Expt 2014-6, there were almost no differences in soil resistance at planting created by the different machines and depths of destoning, with only a slightly higher soil resistance at 30 cm for the shallowest destoning depth than the other two depths (Figure 51).

Figure 51. 2014: Effect of destoning depth on soil resistance at planting in Expt 2014-6. *(a)* Destoner; *(b)* Tillerstar. Depth 1, ■; 4, □; 5, ▲. S.E. bars based on 12 D.F.



In Expt 2014-7, there were no significant differences in soil resistance between the conventional destoner and the Tillerstar (Figure 52). There were significant differences in resistance in both machines at 25 and 30 cm depths where the shallowest destoning depth had higher soil resistance than the two deeper destoning depths.

Figure 52. 2014: Effect of destoning depth on soil resistance at planting in Expt 2014-7. *(a)* Destoner; *(b)* Tillerstar. Depth 1, ■; 4, □; 5, ▲. S.E. bars based on 12 D.F.



4.3.4.5. Ped size distribution

Rather than present data on the grading profiles of different aggregate sizes, two measures of ped size distribution were used to summarize the distribution: mean ped size and the proportion of peds > 6 mm.

In Expt 2014-1, the sandy loam soil had the smallest average ped size of all experiments measured but there was no effect of destoning depth on mean ped size (Table 51) or proportion of peds >6 mm (Table 52) at either planting or harvest. There was also little change in ped size distribution from planting to harvest.

In Expt 2014-2, mean ped size (Table 51) and proportion of peds >6 mm (Table 52) was greater than in Expt 2014-1. There was no effect of destoning depth on mean ped size or proportion of peds >6 mm at either planting or harvest but there was a small increase in mean ped size distribution from planting to harvest (Table 51) even though there was no change in the proportion of peds >6 mm (Table 52).

In Expt 2014-3, mean ped size in the ridge was large owing to the high clay content of the soil but there was no significant effect of destoning depth on mean ped size (Table 51) or proportion of large peds (Table 52). Overall, there was a reduction in ped size between planting and harvest.

Expts 2014-10 and 2014-11 were both clay loam soils but the clay content in Expt 2014-10 was lower (28 %) than in Expt 2014-11 (33 %) and this was reflected in the larger average ped size in Expt 2014-11 than in Expt 2014-10 (Table 51 and Table 52). Mean ped size decreased between planting and harvest in Expt 2014-11 but there was little change over time in Expt 2014-10 (Table 51). There was no effect of destoning depth on ped size distribution in either experiment.

In Expt 2014-12, there was no effect of destoning depth on ped size distribution and there was a slight reduction in mean ped size between planting and harvest (Table 51). The clay soil in Expt 2014-13 produced larger peds than other experiments but destoning depth had no effect on ped size distribution (Table 51 and Table 52). There was a very large reduction in mean ped size between planting and harvest since the large peds > 20 mm broke down into smaller aggregates. There were only 8 % of peds < 2 mm at planting.

Table 51. 2014: Effect of destoning depth on mean ped size at planting and harvest in Expts 2014-1 to 2014-13. S.E. based on 15 D.F.

Sample date	Planting							Harvest						
	Destoning depth							Destoning depth						
Expt	1	2	3	4	5	6	S.E.	1	2	3	4	5	6	S.E.
2014-1	4.0	4.1	4.1	3.8	3.7	3.9	0.38	4.9	3.8	4.6	5.6	3.9	4.0	0.68
2014-2	11.4	10.5	10.3	9.6	9.8	9.8	0.72	12.0	12.4	10.7	11.3	11.2	11.2	1.26
2014-3	12.8	10.9	15.1	10.9	13.9	14.4	1.59	10.5	11.3	10.7	10.2	11.3	10.9	0.90
2014-10	9.4	-	-	9.1	-	8.3	0.27	8.6	-	-	8.7	-	8.6	0.23
2014-11	12.2	-	-	12.9	-	12.8	0.67	11.0	-	-	10.4	-	10.1	0.68
2014-12	7.2	-	-	7.7	-	6.5	0.44	6.8	-	-	6.9	-	5.8	0.43
2014-13	13.8	14.5	-	14.8	-	-	1.29	7.7	7.2	-	-	-	7.2	0.28

Table 52. 2014: Effect of destoning depth on proportion of peds >6 mm at planting and harvest in Expts 2014-1 to 2014-13. S.E. based on 15 D.F.

Sample date	Planting							Harvest						
	Destoning depth							Destoning depth						
Expt	1	2	3	4	5	6	S.E.	1	2	3	4	5	6	S.E.
2014-1	20.4	20.5	20.4	19.0	18.7	18.5	1.82	25.3	18.6	24.6	27.2	20.0	21.3	3.91
2014-2	63.9	59.3	59.2	55.4	58.3	56.2	2.89	62.8	61.3	57.6	56.7	60.2	57.2	3.36
2014-3	59.3	56.3	66.6	55.4	63.9	63.7	4.80	48.4	49.4	49.4	46.2	50.0	51.8	2.62
2014-10	51.4	-	-	48.4	-	46.3	1.16	47.1	-	-	48.4	-	46.2	1.24
2014-11	62.4	-	-	67.8	-	64.8	2.44	54.8	-	-	53.6	-	51.1	3.00
2014-12	38.1	-	-	40.4	-	36.2	1.57	33.9	-	-	35.2	-	30.3	1.52
2014-13	65.0	66.7	-	68.2	-	-	2.77	42.7	40.9	-	40.9	-	-	1.31

Mean ped size was small in both Expt 2014-6 (clay loam) and Expt 2014-7 (sandy loam). In Expt 2014-6, the Tillerstar produced a finer seedbed at planting than the destoner and working the bed at 35 cm (depth 5) resulted in a smaller mean ped size than shallower destoning in both machines (Table 53). By harvest there were no significant effects of machine or depth on ped size distribution but, on average, mean ped size was bigger at harvest than at planting (Table 53).

In Expt 2014-7, at both planting and harvest, destoning at 35 cm using a conventional destoner resulted in smaller peds and a finer seedbed than shallower destoning or using the Tillerstar (Table 53). Mean ped size increased during the season.

Table 53. 2014: Effect of machine and destoning depth on *(a)* mean ped size and *(b)* proportion of peds > 6 mm at planting and harvest in Expts 2014-6 and 2014-7. S.E. based on 12 D.F.

Sample date	Planting							Harvest						
	Destoner			Tillerstar				Destoner			Tillerstar			
Depth	1	4	5	1	4	5	S.E.	1	4	5	1	4	5	S.E.
(a)														
2014-6	7.9	7.9	8.6	6.5	5.9	6.6	0.53	8.7	9.1	10.4	9.5	8.6	7.2	0.77
2014-7	5.7	6.1	4.5	5.2	5.3	5.6	0.30	6.0	6.5	4.7	5.5	5.6	5.9	0.45
(b)														
2014-6	41.5	41.2	44.0	36.3	31.6	36.2	2.53	47.4	46.0	49.0	44.2	41.7	41.6	2.24
2014-7	30.7	30.8	23.0	28.1	27.4	29.9	1.44	32.3	32.4	24.3	29.6	28.8	31.5	2.24

4.3.5. Planting depth and emergence

The intended commercial planting depth was generally achieved for all depths of destoning in all experiments, even for very shallow destoning (Table 54). The coefficient of variation in planting depth was also not affected by destoning depth, indicating that a consistent depth of soil for accurate planting was achieved, irrespective of destoning depth. Shallow destoning did not lead to variable planting depth as is sometimes assumed to be the case when growers find it difficult to achieve adequate soil to form ridges properly. Despite there often being a large difference in texture between the experiments within the same field or within the experiment itself, the experiments in the heavy soil areas were planted at a similar depth to those in lighter areas but there was a trend for greater variation in planting depth along the rows in heavier compared with light areas of fields. There was no effect of treatments on planting depth in Expt 2014-4 (14.0 ± 0.21 cm) or in Expt 2014-5 (14.9 ± 0.19 cm). In Expt 2014-6, machine had no effect but the shallowest cultivation regime was planted slightly shallower than the deepest (Table 54). In Expt 2014-7, there was no effect of machine or depth of destoning on planting depth (Table 54).

Table 54. 2014: Effect of destoning depth on planting depth (cm) in Expts 2014-1 to 2014-3 and Expts 2014-6 and 2014-7

		Destoning depth						
Expt	Intended	1 Shallowest	2	3	4 Commercial	5	6 Deepest	S.E. (15 D.F)
2014-1	15	15.2	15.0	15.4	15.1	15.1	15.3	0.16
2014-2	13	13.8	13.8	13.7	13.6	14.0	13.8	0.16
2014-3	16	15.8	16.2	16.3	16.0	15.9	16.3	0.14
2014-6	15	15.2	-	-	15.4	15.7	-	0.49
2014-7	15	14.5	-	-	13.6	14.5	-	0.52

As might be expected from a generally consistent planting depth, the interval from planting to emergence was not affected by destoning depth in all experiments. In Expt 2014-1, 50 % emergence was 32 days after planting for all destoning depths and there were similar numbers of plants emerged in all strips used to measure emergence, irrespective of depth of cultivation or soil type. A similar lack of effects was observed in Expt 2014-2 sited in the heavier area of the same field. Expt 2014-2 reached 50 % emergence only 1 day after the sandier area in Expt 2014-1, compared with the 8-day differential between the light and heavy areas at the same site in 2013. In Expt 2014-3 there was no effect of soil type or destoning depth on interval from planting to 50 % plant emergence (30-31 days). In Expt 2014-6, 50 % plant emergence was 33 days after planting and 35 days after planting in Expt 2014-7, irrespective of destoning depth and machine. In Expt 2014-13, all destoning depth treatments reached 50 % emergence 30 days after planting.

4.3.6. Tuber yield

4.3.6.1. Cultivation depth experiments

Similar to 2012-2013, increasing destoning depth beyond the commercial depth was generally associated with numerically lower yields, although in individual experiments differences were often not significantly different. In Expt 2014-1, situated in the sandy loam area of the field, depths including and below the commercial depth of destoning had numerically lower yields than shallower depths but the difference was not significant (Table 55). In Expt 2014-2, on the heavy side of the field, there was a trend for yield to decrease with increasing depth below the commercial depth but again the effect was not significant (Table 55). There was no effect of cultivation depth on number of tubers or tuber [DM] in either experiment but the heavier site (Expt 2014-2) had fewer tubers than the light site (Table 55).

Table 55. 2014: Yield, number of tubers >10 mm and tuber [DM] in Expts 2014-1 and 2014-2 (harvested 24 September)

Expt	Destoner depth (cm)	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
2014-1	1 Shallowest	70.6	566	23.5
	2	70.3	572	23.6
	3	70.0	572	23.0
	4 Commercial	67.9	550	23.4
	5	66.8	541	23.1
	6 Deepest	66.6	556	23.2
	S.E. (15 D.F.)	3.46	34.6	0.44
2014-2	1 Shallowest	68.8	491	23.5
	2	68.4	534	24.1
	3	70.3	515	23.4
	4 Commercial	68.5	519	23.7
	5	64.1	493	23.7
	6 Deepest	62.0	493	23.7
	S.E. (15 D.F.)	3.20	24.8	0.52

In Expt 2014-3, yields were numerically lower from cultivation at depths below the commercial depth, but again the effect was not significant (Table 56). There was also no significant effect of cultivation depth on number of tubers or tuber [DM] (Table 56).

Table 56. 2014: Yield, number of tubers >10 mm and tuber [DM] in Expt 2014-3 (harvested 2 September)

Destoner depth (cm)	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
1 Shallowest	52.5	624	22.0
2	53.7	587	21.7
3	50.9	622	21.8
4 Commercial	50.5	600	22.0
5	49.7	590	22.2
6 Deepest	48.6	590	21.3
S.E. (15 D.F.)	2.23	42.6	0.38

In Expt 2014-4, yield in the variable-depth bedforming and destoning treatment was numerically greater than in the fixed-depth bedforming and destoning treatment and yield variation was less in the variable-depth treatment than the fixed-depth (Table 57). There was no apparent effect of depth of bedforming on yield in the variable-depth area but the deepest depth of bedforming was 45 cm rather than the 54 cm in the commercial comparison. The design of this experiment did not allow the effect of variable-depth bedforming to be compared with standard depth but this relatively simple comparison indicates that bedforming shallower and matching depth to soil water content might reduce soil compaction (or alter some other soil property) and thereby increase yield and decrease cultivation costs.

Table 57. 2014: Effect of variable and fixed-depth bedforming on yield (t/ha) in Expt 2014-4 (harvested 29 July)

	Fixed depth	Variable depth
Mean	25.5	28.7
Minimum	20.2	23.9
Maximum	36.9	36.8
S.E.	1.46†	1.52‡

†14 D.F.

‡ 8 D.F.

4.3.6.2. Machine x cultivation depth experiments

In Expt 2014-5, destoning at the commercial depth (35 cm) reduced yield compared with shallower depths (Table 58). The differences were mainly in the 25-45 mm yield rather than an increase in yield > 45 mm. There was no effect of destoning depth or machine on the total number of tubers or tuber [DM].

Table 58. 2014: Yield, number of tubers >10 mm and tuber [DM] in Expt 2014-5 (harvested 31 July)

Machine, Pitch	Destoner depth (cm)	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
Star, Narrow	1 Shallowest	50.2	1026	17.7
	2	51.1	1078	17.4
	4 Commercial	45.4	1027	16.7
Star, Wide	1 Shallowest	48.1	1089	17.3
	2	48.5	1075	17.6
	4 Commercial	46.0	1006	17.3
Web	1 Shallowest	49.2	1068	17.3
	2	47.2	1063	16.7
	4 Commercial	44.1	1064	16.9
	S.E. (16 D.F.)	1.76	51.4	0.46
Mean	1 Shallowest	49.2	1061	17.5
	2	48.9	1072	17.2
	4 Commercial	45.2	1032	17.0
	S.E. (16 D.F.)	1.01	29.7	0.27

In Expt 2014-6 (the heavier of the two sites used to compare conventional destoning with Tillerstar destoning), there was a significantly greater yield at the shallowest depth compared with the deepest, with the commercial depth (4) being intermediate (Table 59). The effect of depth of destoning was similar for both conventional destoner and Tillerstar machines. There was no effect of machine or depth on number of tubers or tuber [DM].

Table 59. 2014: Yield, number of tubers >10 mm and tuber [DM] in Expt 2014-6 (harvested 22 September)

Machine	Destoner depth	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
Destoner	1 Shallowest	83.3	590	22.3
	4 Commercial	81.4	591	21.5
	5 Deepest	77.7	591	21.8
Tillerstar	1 Shallowest	80.7	585	21.9
	4 Commercial	78.2	573	21.8
	5 Deepest	78.9	569	21.7
S.E. (10 D.F.)		1.87	22.7	0.49
S.E. (12 D.F., same machine)		1.30	18.7	0.56
Mean	1 Shallowest	82.0	588	22.1
	4 Commercial	79.8	582	21.7
	5 Deepest	78.3	580	21.8
S.E. (12 D.F.)		1.17	13.1	0.39

In Expt 2014-7 (the lighter site), there was a trend for yield to be greatest at the shallowest depth compared with the deepest depth but the difference was not significant (Table 60). There was no effect of machine or depth on number of tubers or tuber [DM].

Table 60. 2014: Yield, number of tubers >10 mm and tuber [DM] in Expt 2014-7 (harvested 16 September)

Machine	Destoner depth	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
Destoner	1 Shallowest	74.5	460	23.3
	4 Commercial	74.3	438	23.8
	5 Deepest	72.6	440	24.2
Tillerstar	1 Shallowest	74.5	453	23.9
	4 Commercial	71.6	471	23.8
	5 Deepest	71.4	473	23.8
S.E. (10 D.F.)		2.70	14.0	0.65
S.E. (12 D.F., same machine)		2.06	26.6	0.71
Mean	1 Shallowest	74.5	456	23.6
	4 Commercial	72.9	455	23.8
	5 Deepest	72.0	457	24.0
S.E. (12 D.F.)		1.46	18.8	0.50

In Expt 2014-8, there was no effect of depth of bedtilling on yield, but not declodding (destoning) resulted in a lower yield than declodding (Table 61). There was no effect of bedtilling depth or use of a destoner on number of tubers or tuber [DM].

Table 61. 2014: Yield, number of tubers >10 mm and tuber [DM] in Expt 2014-8 (harvested 26 September)

Bedtiller depth	Destoner	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
Shallow	None	58.8	374	22.9
	Destoned	66.1	354	22.2
Deep	None	57.9	324	22.7
	Destoned	67.7	347	23.5
	S.E. (9 D.F.)	3.48	25.4	0.52
Mean	None	58.3	350	22.8
	Destoned	66.9	350	22.9
	S.E. (9 D.F.)	2.46	17.9	0.37

In Expt 2014-9, there was a trend for the non-plough cultivation regime to have a higher yield than ploughed soil (Table 62) but there was no replication of these blocks of different cultivation regimes, so no statistical test could be made. There was a trend for the heavy soil to produce fewer tubers than the light soil but there was no effect of soil type or cultivation regime on tuber [DM] (Table 62).

Table 62. 2014: Yield, number of tubers >10 mm and tuber [DM] in Expt 2014-9. S,E. based on 2 D.F. (harvested 1 October)

Soil type	Cultivation	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
Light	Plough	71.5 (± 2.46)	464 (± 24.6)	22.6 (± 0.11)
	Non-plough	77.9 (± 2.66)	459 (± 25.6)	22.5 (± 0.11)
Heavy	Plough	71.2 (± 3.02)	394 (± 21.2)	22.5 (± 0.09)
	Non-plough	74.8 (± 2.49)	385 (± 19.6)	22.7 (± 0.14)

4.3.6.3. Nitrogen x cultivation depth experiments

The yield data for Expts 2014-10 to 2014-13 are reported fully in the section on soil mineral nitrogen and crop nitrogen uptake, but there were no significant effects of destoning depth on yield.

4.3.6.4. Planter profile experiments

In the planter experiment (Expt 2014-14) there were slightly more plants/ha in the semi-bed (30 700 ± 695) than the trapezoidal profile (27 300) which was unexpected given that the same planter and spacing was used. However, this had no effect on yield or number of tubers and there were no significant effects of bed tilth, ridge profile or hood pressure on yield, number of tubers or tuber [DM] (Table 63).

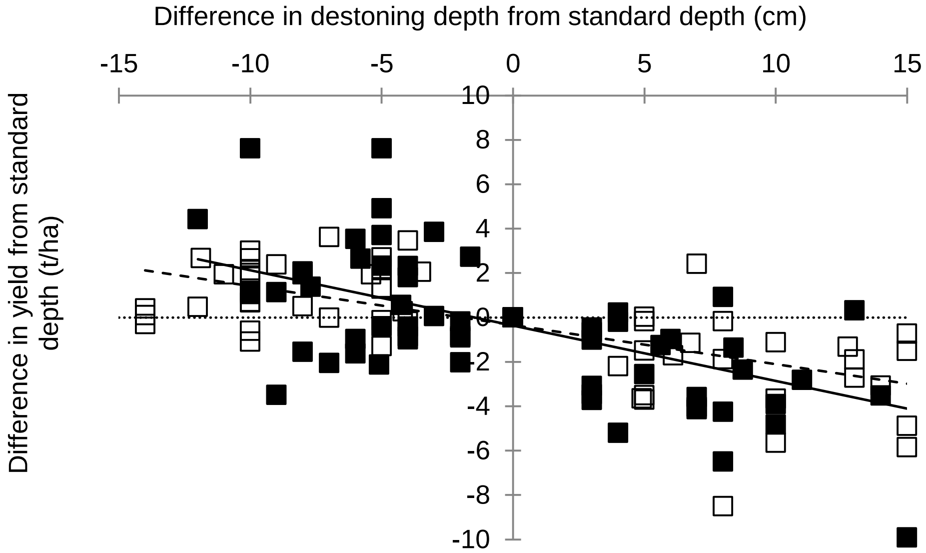
Table 63. 2014: Yield, number of tubers >10 mm and tuber [DM] in Expt 2014-14 (harvested 3 October)

Bed tilth	Ridge profile	Hood pressure	Total yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
Coarse	Semi-bed	High	44.6	447	26.9
		Low	44.5	462	26.3
	Trapezoidal	High	49.5	462	25.9
		Low	46.2	481	25.9
Fine	Semi-bed	High	47.6	491	25.2
		Low	48.4	517	25.8
	Trapezoidal	High	46.2	423	26.1
		Low	45.1	428	26.1
S.E. (14 D.F.)			2.18	42.0	0.92

4.3.6.5. Summary of 2011-2014 effects of destoning depth on yield

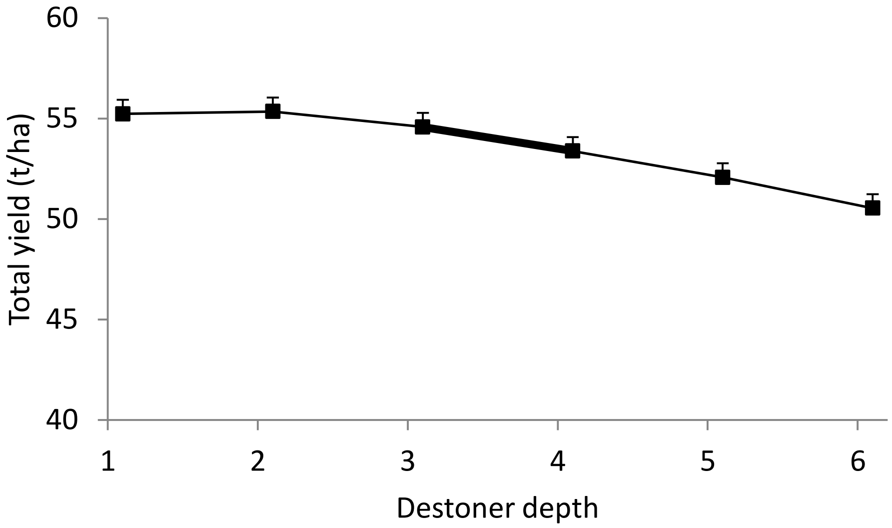
Similar to the results of 2012-2013, there were few statistically significant differences in yield between destoning depths but most experiments had trends for yield to decrease with depth. Figure 53 shows a means of presenting the effect of destoning depth on yield in relation to the standard depth used in the commercial field surrounding each destoning depth experiment over the period 2011-2014. There was a significant negative correlation between depth of destoning and yield and there was a significantly steeper slope for the heavier sandy clay loam, clay loam and clay soils than for the lighter sandy loams.

Figure 53. Effect of destoning depth on yield (difference between actual and standard) in all destoning depth experiments conducted in 2011-2014. SCl-C experiments, ■ and solid line (y = -0.25x - 0.36, R^2 = 0.33); SL experiments, □ and dashed line (y = -0.176x-0.34, R^2 =0.45).



A combined ANOVA using the 16 sites with detailed destoner depth experiments as a factor, indicated a significantly lower yield (50.5 t/ha) when destoning 3-5 cm deeper than the commercial depth (53.4 ± 0.70 t/ha, Figure 54). Numerically, the yields from 22-28 cm depth (55.3 t/ha) were greater than at the commercial depth, although not significantly different but there was no evidence that destoning shallower than commercial depth resulted in lower yield. Whilst it might be expected that yields might be reduced in wet seasons by cultivating soil deeper (where soil would be expected to be wetter) owing to compaction, a positive effect on yield from destoning shallower than the commercial depth would not necessarily be anticipated but a numerical difference was found in all years of the project.

Figure 54. Mean effect of destoning depth on yield in all 16 detailed destoning depth experiments. Thick line section indicates commercial depths.



4.3.7. Soil mineral nitrogen and crop nitrogen uptake

At emergence, the two sites with James Daw, Expts 2014-10 and 2014-11, had the lowest SMN (47 kg N/ha) whilst Expt 2014-12, had the largest (138 kg N/ha) (Table 64). At the final harvest, average soil mineral N ranged from 44 kg N/ha (Expt 2014-11) to 55 kg N/ha in Expt 2014-12. For both Daw sites (Expts 2014-10 and 2014-11), the quantities of SMN in the furrow increased between the spring and autumn sampling and this was in contrast to Expt 2014-12 and Expt 2014-13 and what was found in 2013.

Table 64. 2014: Effect of sample position on soil mineral nitrogen (kg N/ha, to 90 cm depth) on two occasions in Expts 2014-10 to 2014-13. All samples were taken from plots that were destoned at the standard depth and received no N fertilizer

Experiment	Mean	Bed	Furrow	S.E. (3 D.F.)
2014-10				
Emergence 3 June	47	71	24	7.2
Harvest 18 September	54	60	47	5.7
2014-11				
Emergence 3 June	47	70	25	10.7
Harvest 18 September	44	54	33	5.9
2014-12				
Emergence 27 May	138	206	70	23.7
Harvest 3 October	55	61	49	10.4
2014-13				
Emergence 25 May	73	87	59	9.6
Harvest 30 September	45	57	33	5.9

The effects of destoning depth and N application rate on tuber FW yield, tuber and total DM yield and N uptake are shown in Table 65. When averaged over all treatments, yields ranged from 37.1 to 46.5 t/ha in Expt 2014-13 and Expt 2014-12, respectively. At all four sites, tuber FW yield was increased by applying 200 kg N/ha but the size of the response was variable. In Expt 2014-12, 200 kg N/ha was associated with a yield increase of 6.0 t/ha but in Expt 2014-13 the yield increase was 21.6 t/ha. There was no effect of depth of destoning on tuber FW yield in any experiment. Increasing the N application rate from 0 to 200 kg N/ha resulted in significant increases in tuber and total dry matter yield at all four sites but, again, the effects of destoning depth were small, inconsistent and non-significant.

The average tuber N uptake varied from 90 kg N/ha in Expt 2014-13 to 153 kg N/ha in Expt 2014-12. At each site, the application of N fertilizer resulted in an approximate doubling of tuber N uptake and when N had been applied, tuber N uptake ranged from 128 kg N/ha (Expt 2014-13) to 197 kg N/ha (Expt 2014-12). Final harvests were taken when most crops had more or less senesced and there was relatively little N in the haulm (as indicated by the small differences between tuber and total N uptakes). Total N uptake was significantly increased by N fertilizer at all sites. In common with findings from previous seasons, depth of destoning had only small and inconsistent effects on tuber and total N uptake and none of these effects were statistically significant.

On the basis of their texture and previous cropping all these soils would be classified with a Soil Nitrogen Supply Index (SNS) of 0/1 and would be expected to contribute < 80 kg N/ha to crop N uptake. For two of the sites (Expts 2014-11 and 2014-12), the N uptake when no N fertilizer had been applied was > 80 kg N/ha showing that the SNS Index would have underestimated the capacity of the soil to supply N. This observation is consistent with those made in previous seasons and suggests that, in general, the current method of calculating fertilizer requirement underestimates contributions of N from the mineralization of organic matter. The absence of any significant effect of destoning depth on crop nitrogen uptake shows that, within the range of destoning depths tested, similar amount of N were released by the cultivations irrespective of their depth. It was thought that selecting soils with higher clay content in 2014 *c.f.* 2012 and 2013 might result in soil compaction with deeper destoning depths and therefore limit N uptake through the production of sparser root systems. However, collectively, data from 2011 to 2014 showed that, within the limits of normal commercial practice, destoning depth had no effect on crop fertilizer requirement.

Table 65. 2014: Main effects of nitrogen application rate and depth of destoning on fresh and dry weight yields and nitrogen uptake at four locations (Expts 2014-10 to 2014-13). For achieved depths of destoning see Table 45. Harvest dates in ()

		N application rate (kg/ha)			Destoning depth			S.E.
Expt	Mean	0	200	S.E.	1	4 (2)†	6	(15 D.F.)
2014-10 (18 September)								
Tuber FW yield (t/ha)	38.0	31.9	44.1	1.24	37.5	38.2	38.3	1.52
Tuber DW yield (t/ha)	9.6	8.1	11.1	0.29	9.4	9.6	9.8	0.36
Total DW yield (t/ha)	10.7	8.8	12.5	0.31	10.4	10.7	10.9	0.38
Tuber N uptake (kg N/ha)	110	71	149	3.0	111	109	110	3.6
Total N uptake (kg N/ha)	126	82	169	3.1	125	126	126	3.7
2014-11 (18 September)								
Tuber FW yield (t/ha)	44.9	37.3	52.4	1.26	43.1	44.4	47.1	1.54
Tuber DW yield (t/ha)	11.3	9.3	13.2	0.37	10.8	11.4	11.6	0.45
Total DW yield (t/ha)	12.7	10.4	15.0	0.39	12.2	12.8	13.1	0.48
Tuber N uptake (kg N/ha)	132	84	180	7.5	126	135	135	9.2
Total N uptake (kg N/ha)	151	97	204	7.2	143	156	153	8.8
2014-12 (3 October)								
Tuber FW yield (t/ha)	46.5	43.5	49.5	1.30	45.1	48.6	45.8	1.59
Tuber DW yield (t/ha)	12.0	11.3	12.8	0.33	11.6	12.6	11.8	0.40
Total DW yield (t/ha)	13.1	12.1	14.0	0.36	12.6	13.7	12.8	0.45
Tuber N uptake (kg N/ha)	153	108	197	10.8	145	167	146	13.2
Total N uptake (kg N/ha)	168	118	217	11.9	159	183	160	14.6
2014-13 (1 October)								
Tuber FW yield (t/ha)	37.1	26.3	47.9	1.14	38.5	35.0	37.7	1.40
Tuber DW yield (t/ha)	10.2	7.2	13.2	0.32	10.4	9.7	10.5	0.39
Total DW yield (t/ha)	11.4	8.1	14.7	0.35	11.6	10.8	11.7	0.43
Tuber N uptake (kg N/ha)	90	51	128	4.5	91	81	97	5.5
Total N uptake (kg N/ha)	105	61	149	5.0	107	96	112	6.1

†Depth 2 in Expt 2014-13

4.3.8. Tuber quality

Assessments of tuber quality were made on all destoning depth experiments destoned for packing (Expts 2014-1, 2014-2, 2014-3, 2014-5, 2014-6 and 2014-8). There was no effect of destoning depth on greening, cracking or common scab in any experiment examined (Table 66 and Table 67).

Table 66. 2014: Effect of destoning depth on severity (% surface area) of common scab at final harvest in Expts 2014-1, 2014-2, 2014-3, 2014-5, 2014-6 and 2014-8

		Destoning depth						S.E.
Expt	Machine treatment	1 Shallowest	2	3	4 Commercial	5	6 Deepest	(15 D.F.)†
2014-1	-	1.62	1.50	1.75	1.38	1.16	0.86	0.339
2014-2	-	1.97	1.21	1.74	1.12	2.15	1.56	0.514
2014-3	-	1.70	1.43	1.73	1.38	1.35	1.70	0.231
2014-5	Narrow	1.89	1.14	-	1.50	-	-	0.245
	Wide	1.48	1.18	-	1.46	-	-	
	Web	1.11	1.05	-	1.39	-	-	
2014-6	Destoner	1.69	-	-	1.88	1.04	-	0.418
	Tillerstar	1.43	-	-	1.17	1.74	-	
2014-8	No declod	6.22	-	-	4.23	-	-	0.783
	Declod	7.61	-	-	5.49	-	-	

†16, 12 and 9 D.F. in Expts 2014-5, 2014-6 and 2014-8, respectively

Table 67. 2014: Effect of destoning depth on the incidence (%) of tuber greening at final harvest in Expts 2014-1, 2014-2, 2014-3, 2014-5, 2014-6 and 2014-8

		Destoning depth						S.E.
Expt	Machine treatment	1 Shallowest	2	3	4 Commercial	5	6 Deepest	(15 D.F.)†
2014-1	-	3.4	2.3	3.9	1.7	1.5	2.1	0.87
2014-2	-	7.4	8.1	6.3	3.7	5.2	6.0	1.51
2014-3	-	5.6	4.2	5.1	2.1	4.5	4.9	1.08
2014-5	Narrow	4.7	6.7	-	3.3	-	-	1.68
	Wide	4.0	6.7	-	4.0	-	-	
	Web	3.3	2.0	-	1.3	-	-	
2014-6	Destoner	10.4	-	-	7.5	9.1	-	2.56
	Tillerstar	9.2	-	-	6.2	10.6	-	
2014-8	No declod	7.5	-	-	10.0	-	-	2.47
	Declod	11.1	-	-	11.6	-	-	

†16, 12 and 9 D.F. in Expts 2014-5, 2014-6 and 2014-8, respectively

The planter experiment (Expt 2014-14) similarly did not show any effects of bed tilth, ridge profile or planter hood pressure on greening incidence (12.1 ± 1.69 %) or severity (2.0 ± 0.51 % SA). In Expt 2014-14, there was no difference in planting depth between semi-bed and trapezoidal ridge profile and whilst high planter hood pressure and coarse tilth (15.2 ± 0.24 cm) tended to increase planting depth slightly compared with low pressure and fine soil (14.2 cm), these differences in planting depth are small and unlikely to have any direct effect on greening.

These findings confirm the results of 2011-2013 that destoning depth had little effect on the severity of common scab and greening on the wide range of soils studied in the project. Generally, beds for can be much shallower and aggregate size distribution within the ridge can be appreciably coarser without the current standards for common scab or greening becoming an issue. The 2014 site with the largest mean aggregate distribution in the ridge (Expt 2014-8) had the worst scab and greening, so caution needs to be exercised on high clay content soils where clod formation more readily occurs.

4.3.9. Bruising during commercial harvesting

In Expt 2014-5, bruising incidence was low and there was no significant effect of machine type or destoning depth (Table 68).

Table 68. 2014: Blackspot bruising incidence following commercial machine harvesting in Expt 2014-5 (harvested 31 July)

Machine, Pitch	Destoner depth	Bruising incidence (%)
Star, Narrow	1 Shallowest	7.5
	2	8.8
	4 Commercial	5.0
Star, Wide	1 Shallowest	6.3
	2	8.7
	4 Commercial	8.3
Web	1 Shallowest	9.2
	2	4.8
	4 Commercial	4.9
	S.E. (16 D.F.)	1.39
Mean	1 Shallowest	7.7
	2	7.4
	4 Commercial	6.1
	S.E. (16 D.F.)	0.80

In Expt 2014-6, bruising incidence was moderate and there was no effect of the type of machine used for destoning or depth of destoning on internal damage levels during harvesting (Table 69).

Table 69. 2014: Blackspot bruising incidence following commercial machine harvesting in Expt 2014-6 (harvested 22 September)

Machine	Destoner depth	Bruising incidence (%)
Destoner	1 Shallowest	17.0
	4 Commercial	21.4
	5 Deepest	13.6
Tillerstar	1 Shallowest	13.1
	4 Commercial	13.0
	5 Deepest	17.8
S.E. (10 D.F.)		2.88
S.E. (12 D.F., same machine)		3.07
Mean	1 Shallowest	15.0
	4 Commercial	17.2
	5 Deepest	15.7
S.E. (12 D.F.)		2.17

In Expt 2014-15, the incidence of bruising was high and with the harvester share set at the commercial depth, bruising was greater at the shallowest depth than at the commercial depth, though once the harvester share had been raised to account for the shallower bed, bruising became similar across all destoning depths (Table 70). In Expt 2014-16, bruising was very high and whilst there was a trend for shallow destoning to result in more bruising than when harvesting at the commercial depth, the differences were not significant (Table 70). As in Expt 2014-15, matching the harvester share depth to the destoning depth reduced the differences in bruising between the different destoning regimes (Table 70). In Expt 2014-17, bruising was again high and the variable depth harvesting (matching harvester share to destoning depth) resulted in similar incidences of bruising across destoner treatments but there was still a directional trend for shallow destoning to result in more bruising (Table 70).

Table 70. 2014: Effect of destoning depth on blackspot bruising incidence (%) in Expts 2014-15 to 2014-17

		Destoning depth			
Expt	Harvester share depth	1 Shallowest	2	4 Commercial	S.E. (14 D.F.)
2014-15[1]	Fixed	33.9	28.7	26.9	2.11
2014-15[1]	Variable	28.6	23.7	27.8	2.26
2014-16[2]	Fixed	51.5	49.1	43.4	3.13
2014-16[2]	Variable	48.1	45.8	44.5	1.44
2014-17[3]	Variable	36.4	32.2	28.7	3.17
Mean of Variable share depth		37.7	33.9	33.7	-

[1]Harvested 10 September; [2]Harvested 29 September; [3]Harvested 30 September

The stone and clod content removed when harvesting in Expts 2014-15 and 2014-16 was mostly comprised of stone and is shown in Table 71. In Expt 2014-15, when harvesting at the normal commercial depth, very shallow destoning resulted in much more stone being harvested than at deeper depths but destoning at 30 cm (depth 2) was similar to 35 cm (depth 4). When the harvester share depth was matched to the destoning depth, the amount of stone harvested was similar across all treatments (Table 71). The stone data in Expt 2014-15 support the bruising data (Table 70), showing that with adjustment of harvester depth in relation to shallower destoning can result in similar damage levels for shallow and normal-depth destoning. In Expt 2014-16, the stone content was much higher than in Expt 2014-15. As destoning depth increased, with a fixed harvesting depth set at the commercial depth, the quantity of stone on the harvester increased as destoning depth became shallower (Table 71). When the harvester share depth was set to match the depth of destoning, the stone content harvested was reduced in the shallowest two destoner depths but there was still significantly more stone in the shallowest destoning depth (25 cm) than in the commercial depth (depth 4, 35 cm) (Table 71).

Table 71. 2014: Stone and clod content (kg/ha) removed from picking table during harvesting in Expts 2014-15 and 2014-16

		Destoning depth			
	Harvester	1	2	4	S.E.
Expt	Share depth	Shallowest		Commercial	(14 D.F.)
2014-15	Fixed	718	285	167	73.9
2014-15	Variable	182	211	199	22.1
2014-16	Fixed	1791	1341	871	83.1
2014-16	Variable	1022	999	844	54.5
Mean of Variable share depth		602	605	522	-

Once harvesters had been calibrated to match the depth of destoning, the incidence of sliced tubers, assumed to be from insufficient depth rather than vertical intake discs, was almost zero and unrelated to destoning depth. As destoning (and therefore harvesting) becomes shallower, speed of harvesting needs to increase on sandy soils as without doing so, there is less soil cushioning and tubers may roll in webs leading to increased damage. In Expt 2014-17, the sandiest site used in 2014, the commercial rate of harvesting was 5.2 km/h and this was increased to 7.3 km/h for the shallowest destoning treatment. On the heavy soil in Expt 2014-6, harvesting at 3.8-3.9 km/h was possible at 25 and 30 cm destoning depths, whereas only 3.3-3.4

km/h could be maintained at 35 cm. The overall body of data from 2012-2014 shows that it is possible to harvest from beds as shallow as 25 cm but the data indicate there are cases on very stony soils where bruising can be worse than from deeper destoning.

5. Discussion and Conclusions

The cultivation window in spring depends on the soil type and wetness of the soil. In order to produce sufficient soil for a potato seedbed, at least 20 cm of soil is required and on heavier soils, at this depth soil can be above the PL for cultivation. During April, when most potatoes in the UK are planted, the weather can be extremely variable. Although April is often a dry month, the temperature and rainfall can change markedly. Growers often experience the situation of soil being too wet at depth yet drying rapidly on the surface as the day warms up. Cultivation such as ploughing or bedforming brings large clods of wet, unweathered soil onto the surface. This can dry hard within a few hours, necessitating intensive bedtilling operations in an effort to reduce the clod size sufficiently for the destoner to work at an acceptable rate. Without cultivating soil, drying to the depths needed to produce adequate soil for destoning is very slow and growers are left in a quandary: progress with cultivation in the knowledge that soil damage will occur or wait until the soil is fit to cultivate. Therefore, the cultivation window is often narrower than expected. With better knowledge of the critical depths of cultivation on heavier soils, growers would be able to judge a more effective cultivation strategy.

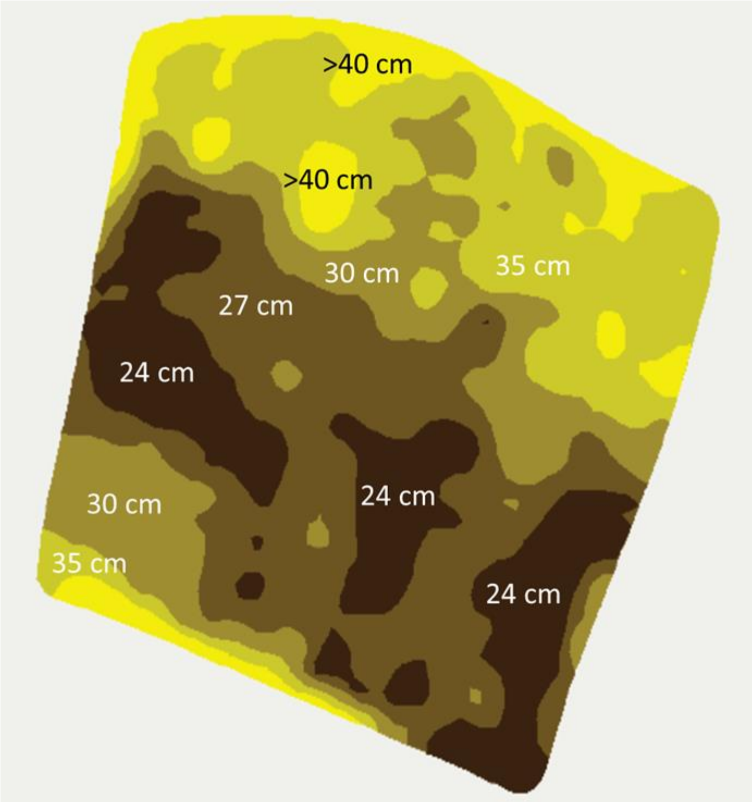
Each season during this project was different in terms of soil wetness at planting. The season prior to the project (2011) was very dry throughout, whilst 2012 ranged from dry to very wet (once the rain set in from 9th April). In 2013, soils were generally wetter at cultivation depth during late March and early April than in the previous two years. In 2014, following a wet summer and very wet winter, soils were denser and wetter at similar depths than in the previous three seasons. This variation in the wetness and bulk density of soil affected the critical depth of cultivation. As an example, in three closely-adjacent fields at the GVAP Raveningham site (Expts 2012-2, 2013-2, 2014-2), there was a 5 cm variation in the critical depth of cultivation in a sandy clay loam textured soil between the three seasons (Table 72). The higher the clay content, the closer the critical depth to the surface for avoiding compaction. In Expt 2014-2, the shallow depth of soil available would have limited the depth of destoning without plastic compaction to < 25 cm.

Table 72. Critical depth for cultivation of sandy clay loam soil in Expts 2012-2, 2013-2 and 2014-2

Expt	Clay content of top 30 cm (%)	Organic matter (%)	Depth below bed ridge (cm)	Depth in relation to flat surface (cm)
2012-2	19	1.5	32	24
2013-2	22	2.2	30	22
2014-2	26	1.8	28	19

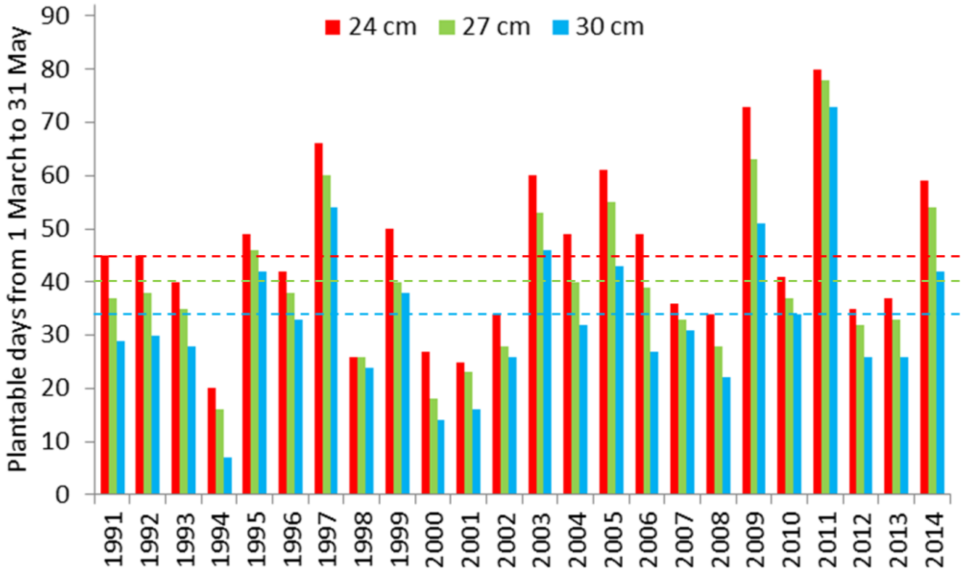
Using data from EC scans, soil texture, organic matter and Equation 13 from Keller & Dexter (2012) to calculate the PL variation across a field, a map of critical destoning depth can be constructed, as shown in Figure 55. Having such maps would guide growers and operators over the optimum destoning depth and allow them to adjust machinery depth on the move if the tractor has access to reasonable accurate (± 2 m) GPS location data. This approach of variable cultivation depth related to soil type could lead to significant improvements in yield which could pay for the technology required to implement, especially since EC maps, once created, give guidance on likely soil boundaries for all subsequent cultivations, not just the potato crop.

Figure 55. Map of critical cultivation depth in GVAP The Cliff field superimposed on EC map. Depths relate to the depth of destoned bed capable of being produced without plastic compaction. Data derived from Expts 2014-1 and 2014-2.



An extension of this work allows the length of the workability window to avoid soil damage to be calculated. Taking a representative sandy clay loam soil at Cambridge University Farm, calculations were made to estimate the number of days in March, April and May when soil could be cultivated at different depths without causing plastic damage to the soil whilst ploughing or rotary cultivating. In the driest seasons (e.g. 2011), 75 days would be available to plough to 30 cm depth out of a possible 91 but in the wettest seasons (e.g. 1994, 2000 or 2001), < 15 days would be available for cultivating without the risk of shearing compaction (plastic deformation) of wet soil (Figure 56). The average, based on 1991-2014, shows that only around 34 days would be available to plant if cultivating took place at 30 cm. By reducing the cultivation depth, this window would increase to 40 days at 27 cm and 45 days at 23 cm. The latter depth would be sufficient, except on very stony soils, to produce beds 28 cm deep prior to planting.

Figure 56. **Effect of cultivation depth, d, on number of plantable days without soil damage at Cambridge, 1991-2014. Conditions: sandy clay loam, soil below plastic limit at d cm, < 3 mm rainfall on day of cultivation).**



When taking all the data into consideration from 2011-14, destoning 5-9 cm shallower than the standard depth used by growers on sandy soils (30-38 cm) resulted in no yield loss. The project suggests that optimum destoning in such soils is close to 27-28 cm, with no issues relating to planting depth, emergence, tuber quality and, on the majority of sites, no reduction in harvestability or increases in bruising. When comparing best practice versus current commercial practice on heavier soils (e.g. sandy clay loams, clay loams and clays), destoning 3-5 cm shallower than commercial practice (28 cm) would actually result in a small yield increase. The decrease in yield observed when destoning deeper than standard current practice should be a serious concern for growers as the yield losses as a consequence on compaction and impeded drainage can be large (> 10 t/ha).

Growers often think that shallow destoning will result in shallower than optimum planting but this was not the case. Even in destoned beds as shallow as 20 cm, sufficient soil was present to plant large seed (> 50 mm) at a depth of 17 cm. Indeed, in only two experiments was planting depth significantly shallower than the grower requested and these were both sited on soils where the PL was shallower than all but the two shallowest destoning treatments. In this case, this resulted in insufficient differential between the top of the bed and wheelings and the planter could not as a consequence cover tubers even though there was plenty of soil depth within the bed. Analysis of the variability of planting depth within plots of different destoning depths showed that deeper than standard commercial practice resulted in more variable seed depth than shallower destoning as a consequence of deep destoning leaving an uneven profile across the bed.

The difficulty in producing a clod-free seedbed from traditional working depths on heavier soils which are close to their plastic limit may be significantly reduced by bedforming and destoning 3-5 cm shallower than many growers currently do and this presents few risks to productivity or quality. Growers frequently strive for an unnecessarily deep seedbed on heavier soils and in doing so they lift overly-wet soil with the destoner share onto separating stars or webs which then largely gets transported into the adjacent furrow to be compressed by then next pass of destoning. This reduces the differential in height between the top of the destoned bed and the wheeling which with some makes of planter leads to difficulty in covering seed tubers owing to outside covering bodies lifting the planter out of the soil. This is often combined with variable bed depth when destoning deeply and can lead to variation in planting depth and emergence. On heavier-textured soils, a good correlation was observed between the critical depth for destoning as measured by the PL and the quantity of soil (not stone) being deposited in the furrow having failed to be worked into aggregates of suitable size. If a destoner operator was to gradually increase the depth of working, they would be able to observe the sudden change in soil being placed in the furrow and this would indicate that they were close to the critical depth for cultivation.

Over-working soils by destoning at depths >30 cm sometimes resulted in looser soil within the ridge than shallow destoning but by harvest this extra porosity had frequently been lost and soils were more dense that where destoning was carried out at shallower depths. There were small benefits in reduced soil resistance and lower bulk density resulting from destoning more deeply, however these did not translate into improvements in yield or quality. In summary, destoning depth had little significant effect on ridge density and densities increased from planting to harvest, with the change in density over time not being affected by cultivation regime. However, a number of experiments did show a trend for deeper destoning to result in more consolidation and slumping of the ridge during the season, which would be another good reason for not cultivating soil too deeply.

The higher clay content soils had lower ridge bulk densities than sandier soils, and generally the greater the clay content, the greater the increase in density during the season, with up to 35 % increase in density in the highest clay content soil. The sandiest sites, whilst having high ridge densities at planting, often exhibited smaller changes in ridge density during the season. It should be emphasized, however, that the ridge densities of clay soils at planting were very low and did not increase to the density of sandy soils despite slumping: they remained porous and loose right through until harvest. The clay soils had the highest OM content (3-4 %), which would have contributed to ped formation and stability. Perhaps contrary to perceived views, very shallow destoning on heavy soils (>20 % clay content) often resulted in ridges composed of smaller peds with fewer very large (>35 mm diameter) peds than ridges created from soil destoned deeper than *c*. 35 cm. Mean ped size increased from planting to harvest in heavy soils as fine particles of soil (increased by aggressive, deep destoning) re-aggregated during the season. Additionally, working soils close to, or above, their PL resulted in the formation of clods of the size which were left in the ridge rather than being deposited in the wheeled furrows.

Despite considerable differences in the depths of destoning in each experiment, there were only small changes in soil resistance measured at planting and the reductions in soil resistance with deeper destoning were contrary to the directional effects on yield. Where compaction was created at planting by destoning deeper than the critical depth, this might only manifest itself as the soil dried and became harder in the compacted zones and this would not have been picked up by only measuring soil resistance at planting. The measurements of bulk density throughout the profile showed similar trends to soil resistance and again in the opposite direction to expected when looking at the observed yield versus destoning depth.

An overall improvement in rate of work of *c*. 40 % was achieved by destoning 9 cm shallower than the commercial depth, which speeds up what is often the rate-determining step in the planting operation. Even destoning at a depth of 27-28 cm, the rates of work were c. 20 % greater than current commercial depths. There were significant savings in fuel (e.g. £6-11/ha, based on £0.71/l) from cultivating beds shallower but the costs savings per tonne of harvested tubers was small (*c*. 10-20 p/tonne). More importantly, shallower destoning would give greater opportunity for soils to be cultivated closer to their optimum soil water content as well as reducing the wear on machinery and lowering labour costs. Additionally, producing beds for deep destoning requires deep primary cultivations and this is where further savings in fuel can be made, of the order of 50 %, worth another £5-10/ha (10-20 p/tonne). The whole system of shallower beds ideally needs to be matched to overall shallower primary cultivation to achieve the most effective cost savings and benefits to soil and crop performance.

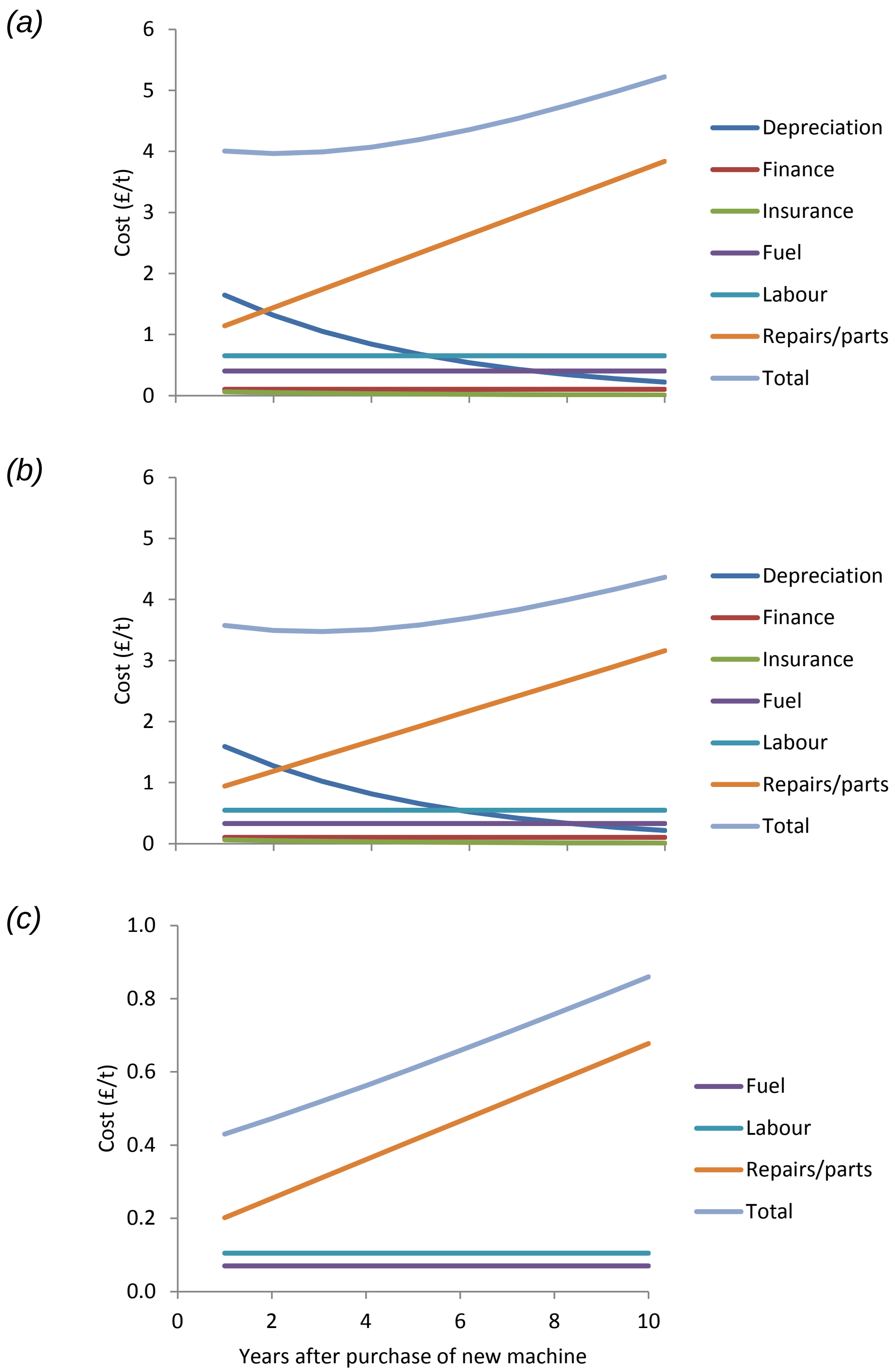
As a consequence of the slow speed of working, large-scale operations frequently operate two or more destoners following each other. At each end of the field, these destoners have to wait for the last machine in line to finish destoning the bed that it is working on before returning back down the field. Often, the slowest machine is at the back of the queue and this leads to a considerable waste of time when turning round, and the shorter the fields, the greater the proportional loss of working time. Several studies were done timing the working and idle time of two, three and four-machine destoner systems. With a single machine working a field of 6 ha (c. 250 m x 250 m), around 82 % of the time was spent destoning soil whilst the overall rate of work of a two-machine system was only *c*. 77 % of the spot rate average of both machines. When the number of machines was increased, the overall rate dropped to *c*. 75 % of the spot rate with three machines and *c.* 72 % with four. Where there is a large differential in the work rates of individual destoners, or where there are three or more machines operating, it would be better working destoners in ‘lands’ (i.e. confining each destoner to blocks of soil which they work individually) to improve their overall work rate. Growers are cautious of having too many ‘joins’ in fields where double the quantity of stone or clod has to be deposited in a single furrow, however, the ‘join’ effect can be reduced by destoning slightly shallower in the two beds either side of the join or making the joins coincide with spray wheelings. Even beyond this, the project highlighted that many growers and managers do not realise that three identical destoners following one another in adjacent beds frequently produce beds of significantly different depth depending on the operator and this is a potential area for training operators.

Potato planting involves the use of highly-specialized and often expensive machinery. Accountants, insurers and machinery dealers mostly use a standard depreciation rate of 20 % p.a. for machinery. A destoner working the same number of hectares each season as a machine working 5-6 cm deeper would probably be in better overall condition (and therefore worth more) after 5 years, when the machine would have been fully written-down. Its trade-in value would be more but it is difficult to extract these data from machinery sales. However, destoning, particularly on stony soils and when working deeply, causes significant wear on stars, webs and bearings. These are costly in terms of parts and labour, but the loss of working time if breakdown or replacement needs to occur during planting can be even more costly to the business and to meeting the optimum planting window for soil conditions and length of season. In collaboration with a manufacturer of destoning machinery, two contractors supplying destoners, three large-scale potato businesses, a machinery consultant and an agricultural economist, it has been possible to calculate repair, parts and depreciation costs as well as fuel and labour costs for a stony, sandy soil and examine the economic effect of changing destoning depth from the current practice to the optimal depths suggested by this report.

A number of parameters needed to be set for the cost study. An area of 120 ha of stony, sandy loam soil, growing 55 t/ha at the optimum destoning depth, was destoned using a single new Grimme Combistar CS150, purchased new in 2015 for £52,500, which was towed by a John Deere 6930 tractor. Using an overall rate of 82 % of the spot rate of destoning, 12-hour days (allowing 0.5 hours per day for machine servicing and repair) and a 6-day working week, shallow (28 cm) destoning would complete the 120 ha c. 4 days faster than the standard commercial-depth (34 cm) destoning. Annual depreciation was calculated at 20 % and finance for purchasing a new machine was based on $^{2}/_{3}$ of the new price (since a machine would have a trade-in value of $^{1}/_{3}$ its new price after 5 years) and 2 % p.a. loan rate. Insurance was based on £8/£1000 of machine value (Bill Basford, personal communication). Fuel cost was averaged over the 3 years of the project at £0.71/l and skilled labour at £14.32/h. The servicing and repair costs of one destoner manufacturer, two contractors and three growers were examined and a cost calculator based on machine age formulated for repairs and parts.

Averaged over 10 years following the purchase of a new star destoner, for standard commercial depth destoning, the cost of destoner repairs and parts have been calculated at *c*. £2.49/t (£142/ha) based on a yield of 55 t/ha, out of a total cost for depreciation, fuel, labour, finance and insurance of £4.41/t (£248/ha). Reducing the depth of destoning to 28 cm reduces the total cost to £3.77/t (£213/ha), of which repairs and parts contribute £2.05/t (£117/ha). Reduced fuel, labour and repairs and parts of shallower destoning contribute 7, 11 and 44 p/t cost savings, respectively, compared with standard-depth destoning. The changes in the costs per tonne are shown in Figure 57. Destoning shallower would allow cultivation to be timed better with respect to soil conditions and this project suggests this could be worth *c*. 1.8 t/ha and this has been taken into account in this cost study. However, in wet springs when planting can be delayed well into May, thereby incurring a yield loss owing to a truncated growing period, the ability to travel 20 % faster with shallower destoning could have a much larger effect on yield.

Figure 57. Calculated costs for destoning at *a)* 34 cm; *b)* 28 cm and *c)* difference 34 cm vs 28 cm for a single Grimme CS150 destoning 120 ha of stony sandy loam soil. Yields used: 34 cm, 53.2 t/ha; 28 cm, 55 t/ha.



The data the N x cultivation depth experiments suggest that the SNS of many potato soils is underestimated by the current Index system and this, in part, may be due to the intensity of the cultivation used to create potato seed beds. There was a very large variation in the quantity of available soil N at emergence following planting in unfertilized soils. For an N Index 0 soil (following cereals), the range in N at emergence in the N x cultivation experiments sited on mineral soils ranged from 69-138 kg N/ha, *c.f.* the RB209 (Anon 2010) average of 60 kg/ha. Clearly, more work is needed on understanding why certain soils mineralize more N than others, even in similar rotations. The range in soil OM could explain only a small part of these differences. However, the apparent lack of effect of depth of destoning on SMN and crop N uptake in all experiments is of interest and may be due to most soil OM being in the top 25 cm of the soil profile. Therefore, when compared to shallow cultivation, deep cultivations do not expose significantly more OM to oxidation and encourage more microbial activity and therefore the subsequent release of inorganic N is similar for a range of destoning depths. Collectively, data from 2011-2014 suggest that, within the limits of commercial practice, altering destoning depth will not alter N fertilizer recommendation.

Despite most experiments from 2012-2014 showing no effect of destoning depth on bruising, on sites selected for high stone content in 2013 and 2014, there were significant effects of increased incidence of bruising where destoning was carried out shallower (e.g. 25 cm depth) than the commercial depth (*c*. 35 cm). This effect was reduced where the harvester share was raised to work in the destoned area of the ridge (which reduced the amount of stone carried through the harvester) but there were instances where bruising was still worse with very shallow destoning than with commercial-depth destoning and this indicates careful consideration is required on very stony sites. The risk of having sharp-edged stones damaging rubber separation rollers is an important consideration and irreparable damage can occur in very short periods when stone content is high. However, growers continue to destone deeper than necessary in areas of fields with low stone content and this problem needs to be addressed if the practice of shallower destoning is to be fully adopted.

Once harvesters had been calibrated to match the depth of destoning, the incidence of sliced tubers, assumed to be from insufficient depth rather than vertical intake discs, was almost zero and unrelated to destoning depth. As destoning (and therefore harvesting) becomes shallower, speed of harvesting needs to increase on sandy soils as without doing so, there is less soil cushioning and tubers may roll in webs leading to increased damage. In Expt 2014-17, the sandiest site used in 2014, the commercial rate of harvesting was 5.2 km/h and this was increased to 7.3 km/h for the shallowest destoning treatment. On the heavy soil in Expt 2014-6, harvesting at 3.8-3.9 km/h was possible at 25 and 30 cm destoning depths, whereas only 3.3-3.4 km/h could be maintained at 35 cm. The overall body of data from 2012-2014 shows that it is possible to harvest from beds as shallow as 25 cm but the data indicate there are cases on very stony soils where bruising can be worse than from deeper destoning.

In conclusion, the project has shown that there is great potential for reducing the depth of cultivation, particularly destoning, with no loss in yield or quality and saving in costs. Soil should not be cultivated deeper than is necessary to produce destoned beds of *c*. 27-28 cm in depth prior to planting and destoning deeper than 35 cm on sandy soils and deeper than 28 cm on heavy soils will result in reduced yields. Destoning to produce beds at 27-28 cm gives greater opportunity for soils to be cultivated closer to their optimum soil water content. On heavier soils, the penalty for cultivating below the critical depth can be greater (i.e. 3-5 t/ha), so destoned beds as shallow as 22-24 cm can result in improved yields and yet still provide sufficient soil to plant and harvest tubers with minimal damage. The difficulty in producing a clod-free seedbed from traditional working depths on heavier soils which are close to their plastic limit may be significantly reduced by bedforming and destoning shallower than many growers currently do and this presents few risks to productivity or quality. In wet springs when planting can be delayed well into May, thereby incurring a yield loss owing to a truncated growing period, the ability to travel 20 % faster with shallower destoning could have a much larger effect on preventing yield loss.

The SNS used to determine N requirements should not be adjusted for the depth of cultivation but it should be recognised that the current system underestimates the SNS of many potato soils and this, in part, may be due to the intensity of the cultivation used to create potato seed beds, even at shallow depths of destoning. Seedbeds can be made appreciably coarser and shallower than current practice before any significantly increased risk of common scab or greening. In very stony fields or stony areas within fields, careful consideration to destoning depth is required to avoid bruising and mechanical damage to tubers but other fields or other areas fields should not be destoned as deeply if they are less stony. Harvester operators would need to pay closer attention to depth but variable depth destoning would benefit yield and soil structure.

Shallower destoning reduces the wear on machinery and results in lower repair and depreciation costs and decreases the chance of breakdown during the planting season. Large savings in labour costs can be made through faster work rates and significant savings in fuel can be made by destoning beds shallower than is currently being practiced. For the most cost-effective solution and to maximise the benefits to soil and crop performance, the whole system of shallower beds needs to be matched to overall shallower primary cultivation.

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7. ACKNOWLEDGEMENTS

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8. APPENDIX

Figure 58. 2012: Location of Expts 2012-1 (red area) and 2012-2 (blue area) shown on the EC map (0-40 cm depth) taken by SOYL in February 2012.

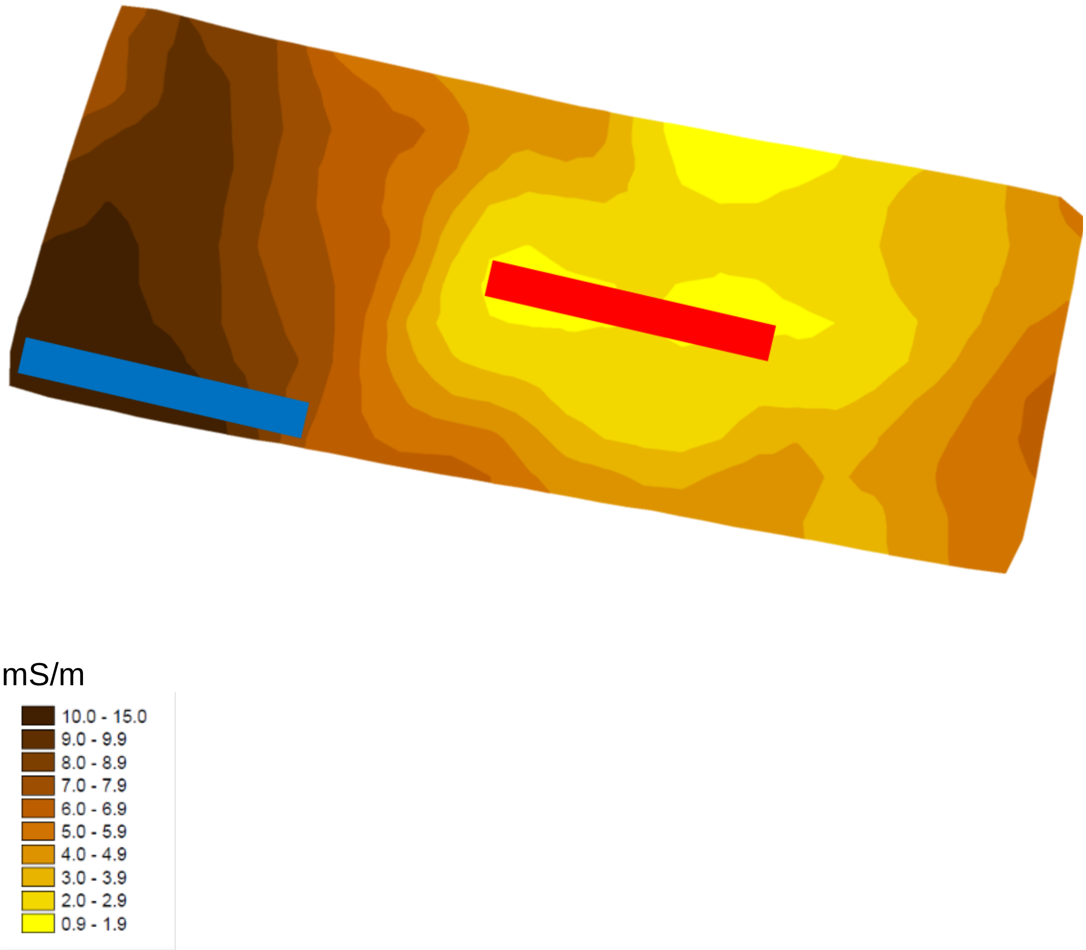


Figure 59. 2012: Location of Expts 2012-3 (red area) and 2012-4 (blue area) shown on the EC map (0-40 cm depth) taken by SOYL in February 2012.

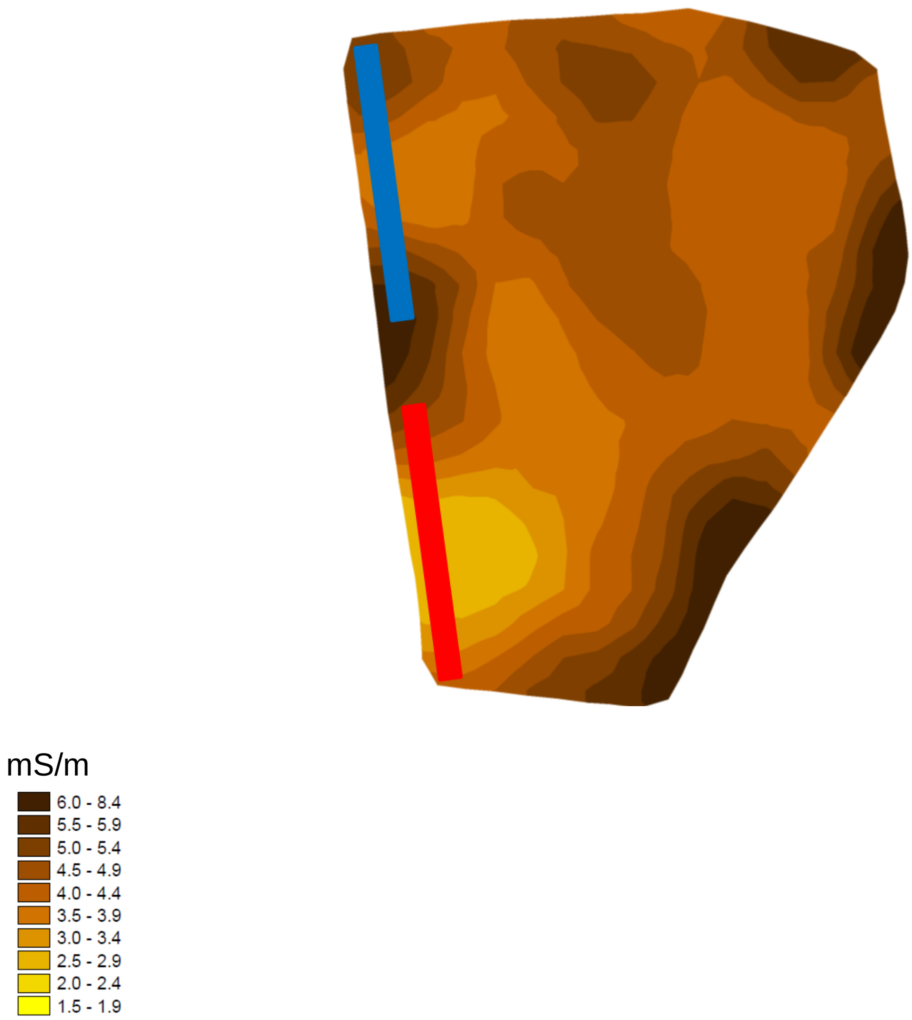


Figure 60. 2012: Location of Expts 2012-5 (red area) and 2012-6 (blue area) shown on the EC map (0-40 cm depth) taken by SOYL in February 2012

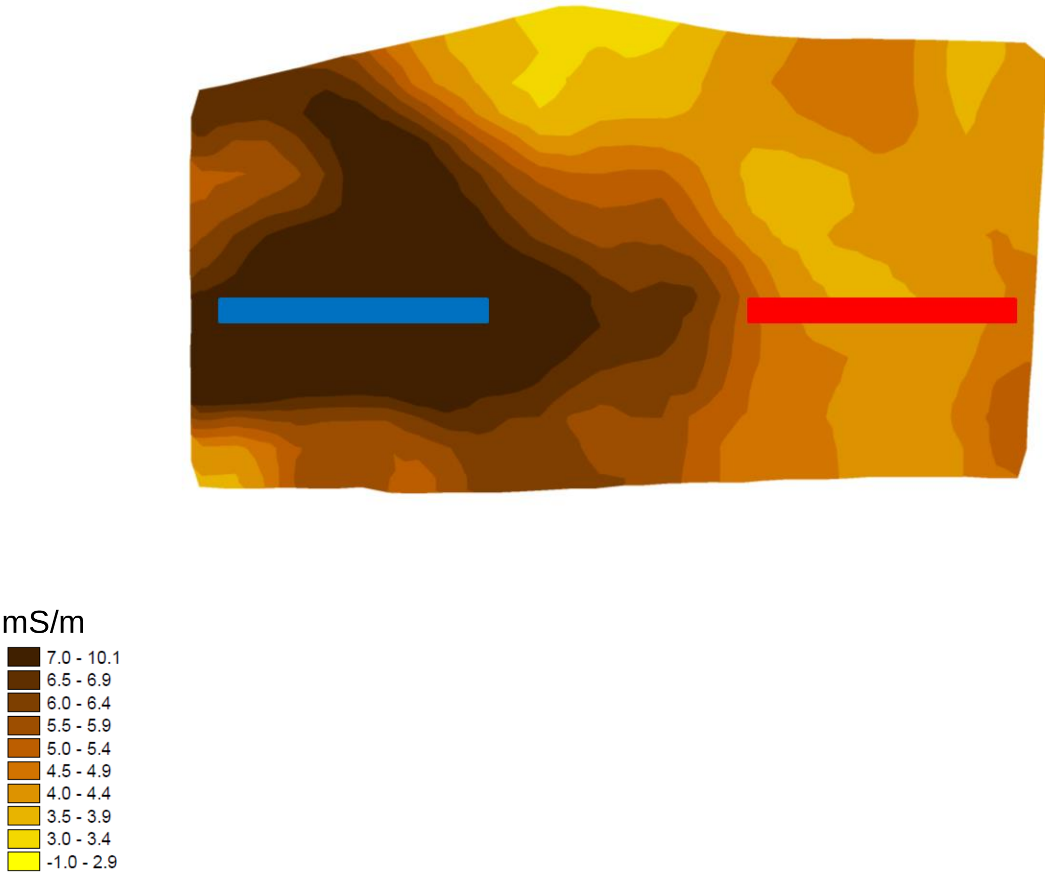


Figure 61. 2012: Location of Expt 2012-8 (blue area) shown on the EC map (0-40 cm depth) taken by SOYL in February 2012.

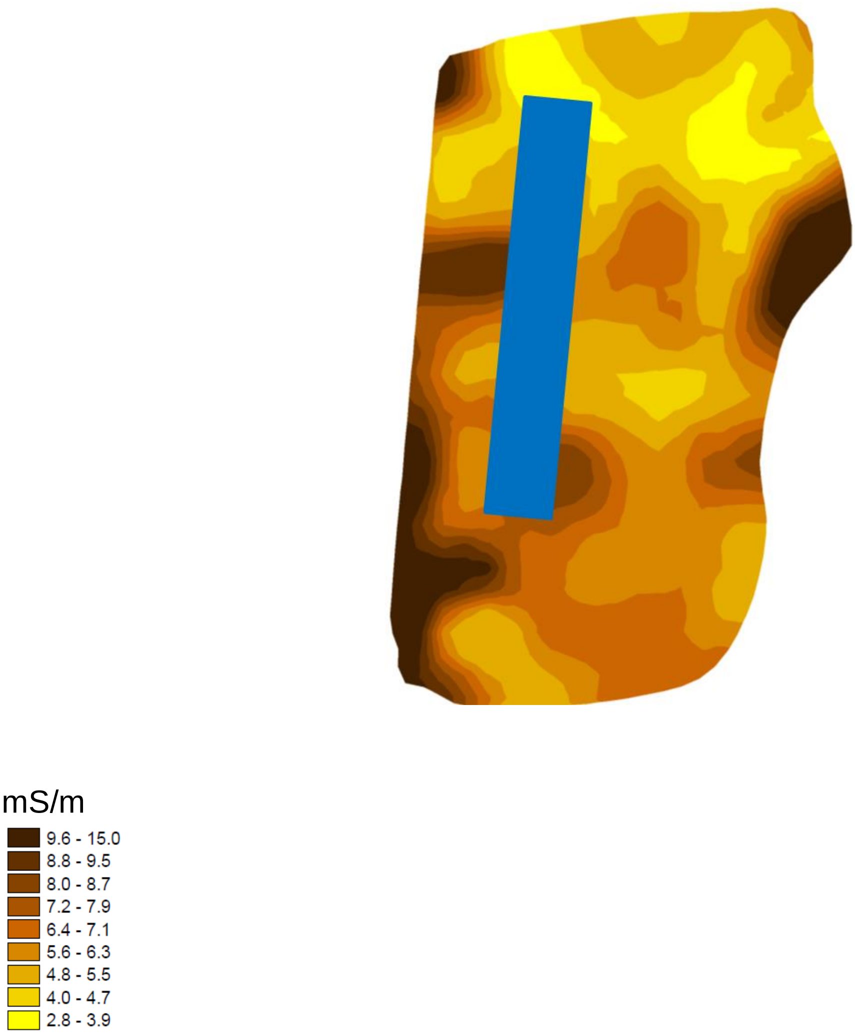


Figure 62. 2012: Location of Expts 2012-10 (red area) and 2012-11 (blue area) shown on the EC map (0-40 cm depth) taken by SOYL in February 2012.

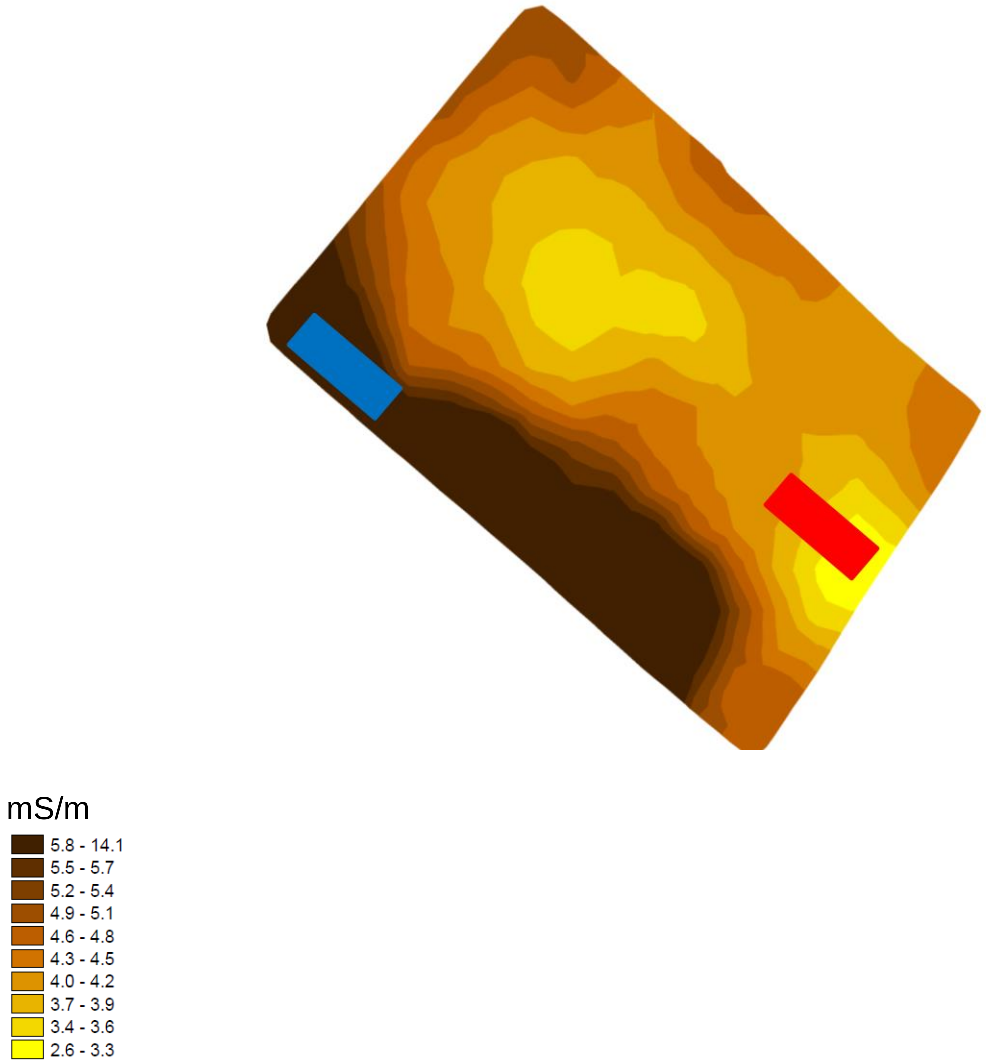


Figure 63. **2013: Location of Expts 2013-1 (red area) and 2013-2 (blue area) shown on the EC map (0-40 cm depth) taken by SOYL in August 2012.**

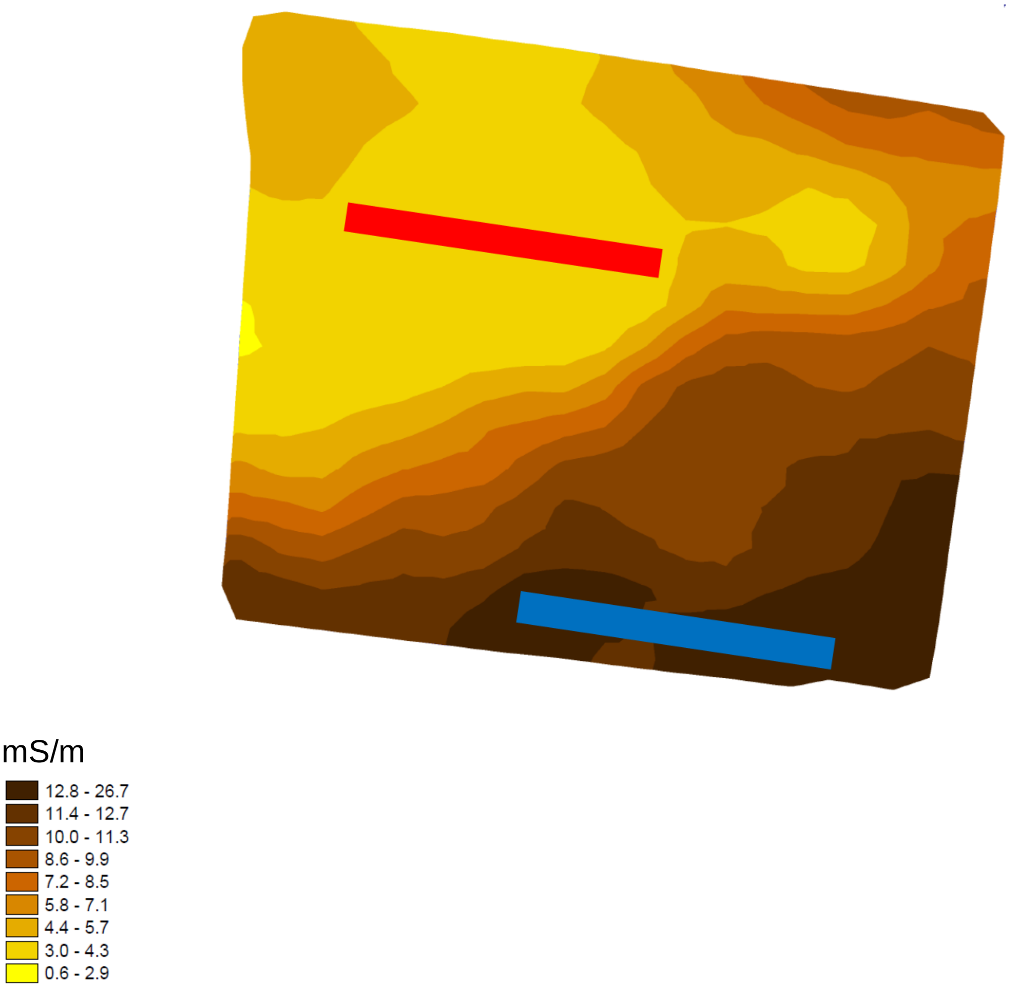


Figure 64. 2013: Location of Expts 2013-3 (red area) and 2013-4 (blue area) shown on the EC map (0-40 cm) taken by SOYL in April 2013.

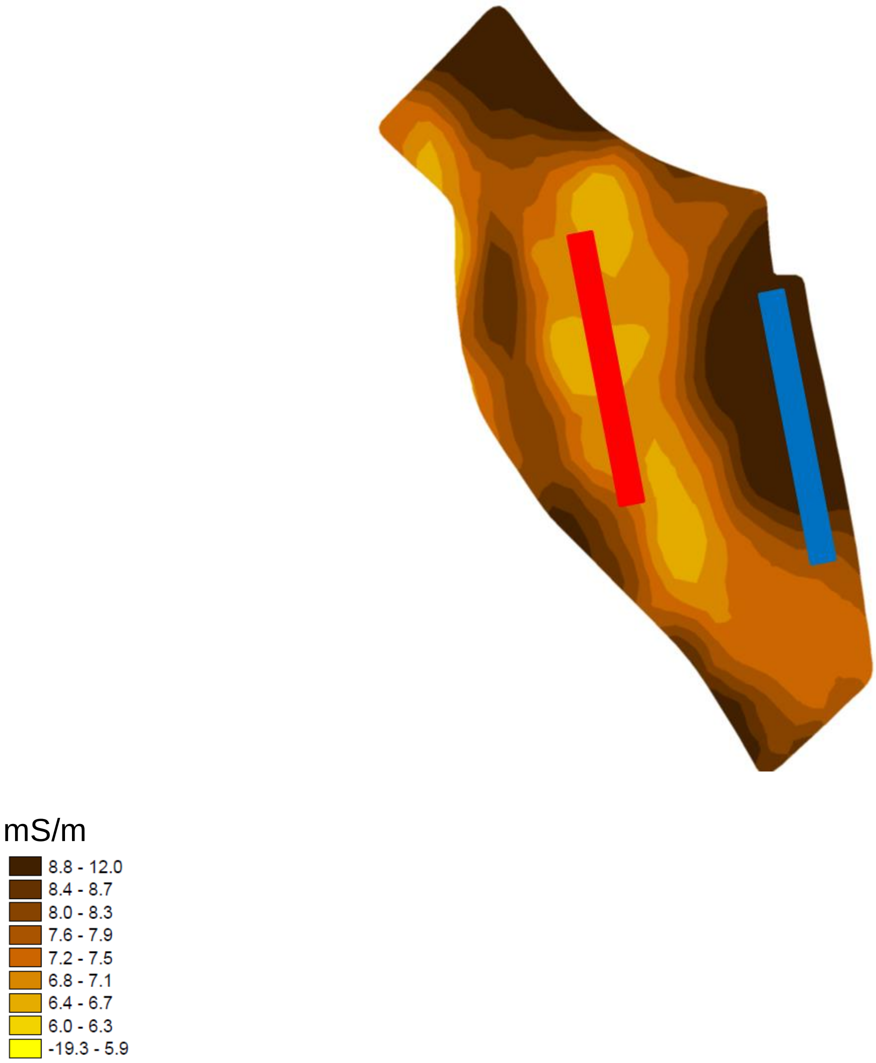
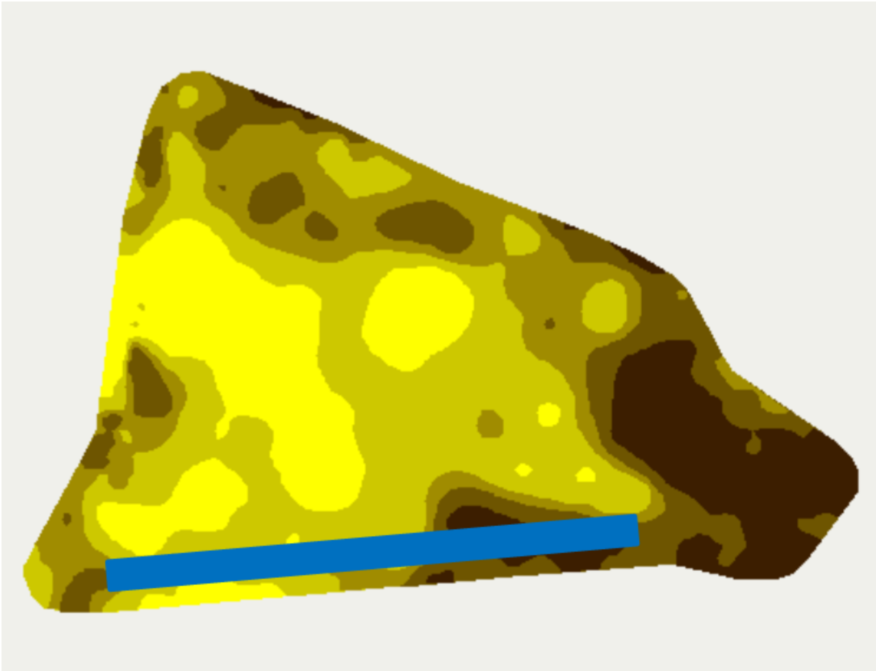


Figure 65. 2013: Location of Expt 2013-7 (blue area) shown on the EC map (0-30 cm) taken by SoilQuest in April 2013.



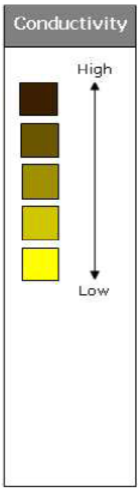
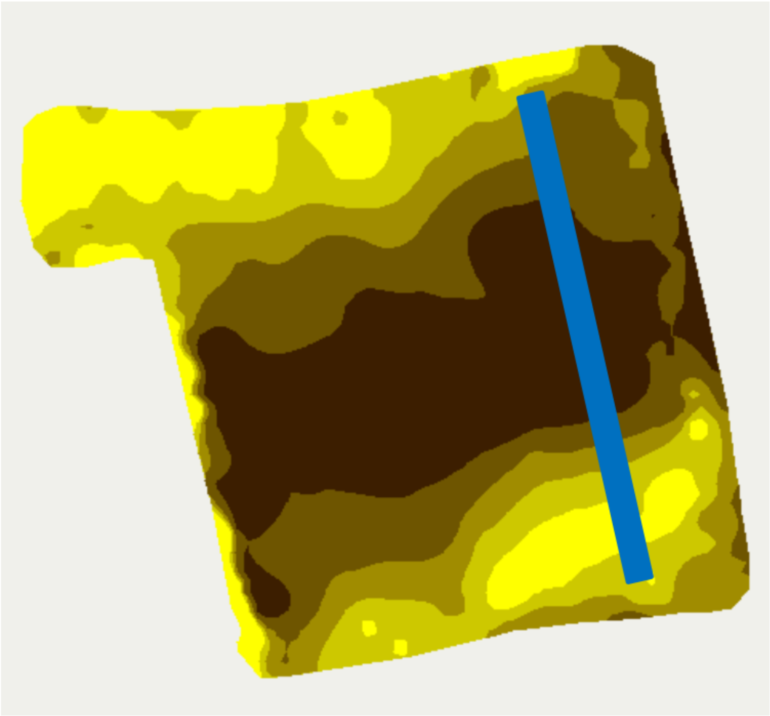


Figure 66. 2013: Location of Expt 2013-8 (blue area) shown on the EC map (0-30 cm) taken by SoilQuest in April 2013.



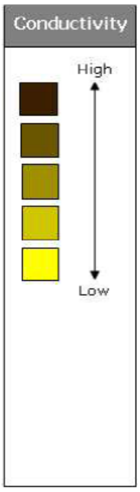


Figure 67. 2013: Location of Expt 2013-10 (blue area) shown on the EC map (0-40 cm) taken by SOYL in March 2013.

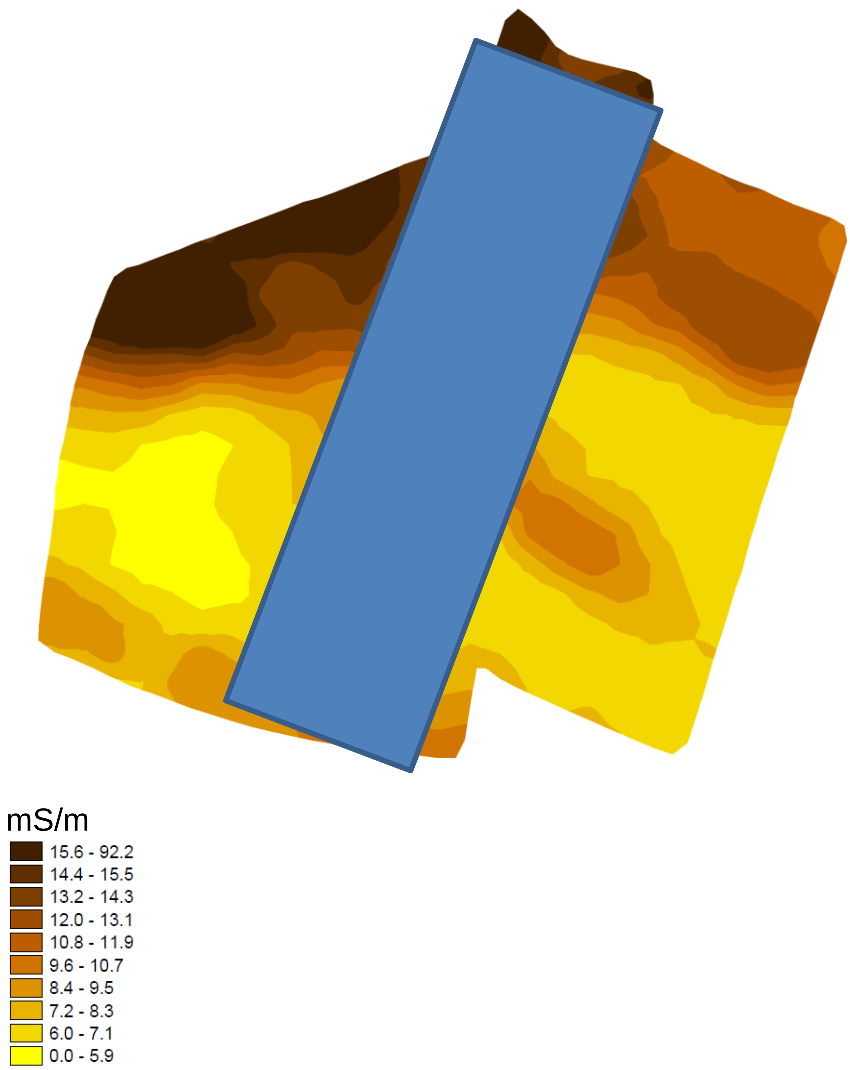
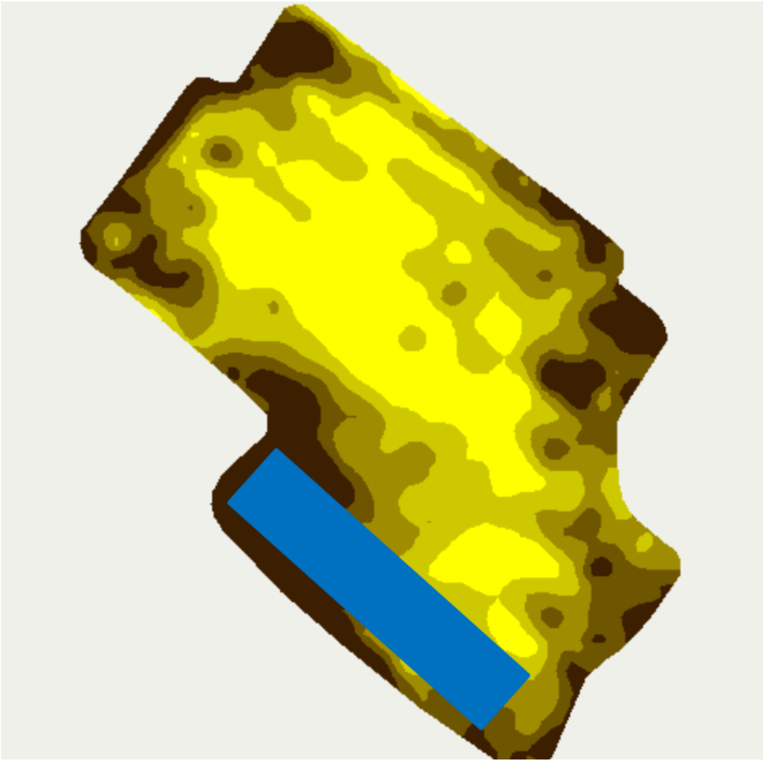


Figure 68. 2013: Location of Expt 2013-12 (blue area) shown on the EC map (0-30 cm) taken by SoilQuest in October 2012.



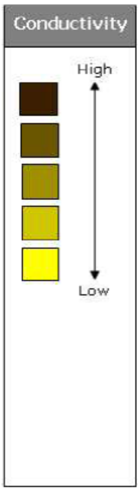


Figure 69. 2013: Location of Expt 2013-17 (blue area) shown on the EC map (0-40 cm) taken by SOYL in March 2013.

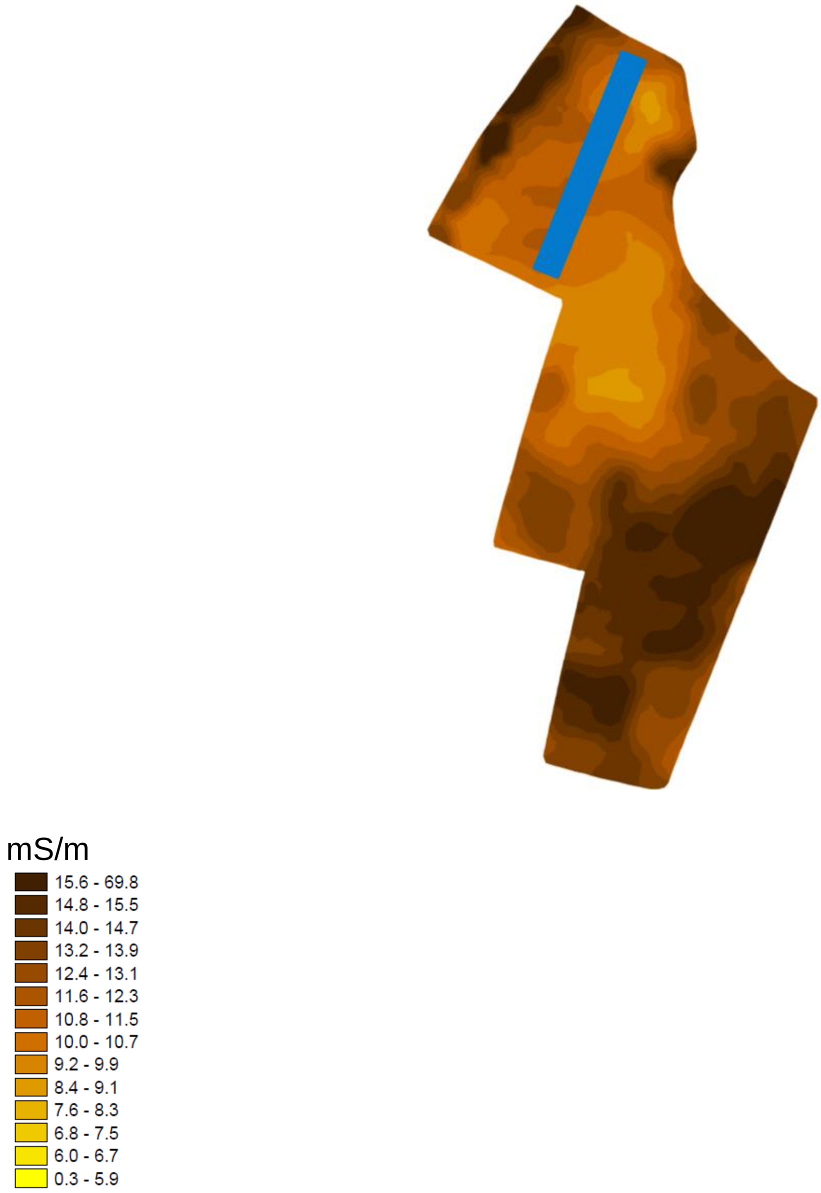


Figure 70. 2014: Location of Expts 2014-1 (red area) and 2014-2 (blue area) shown on the EC map (0-30 cm) taken by SoilQuest in September 2013.

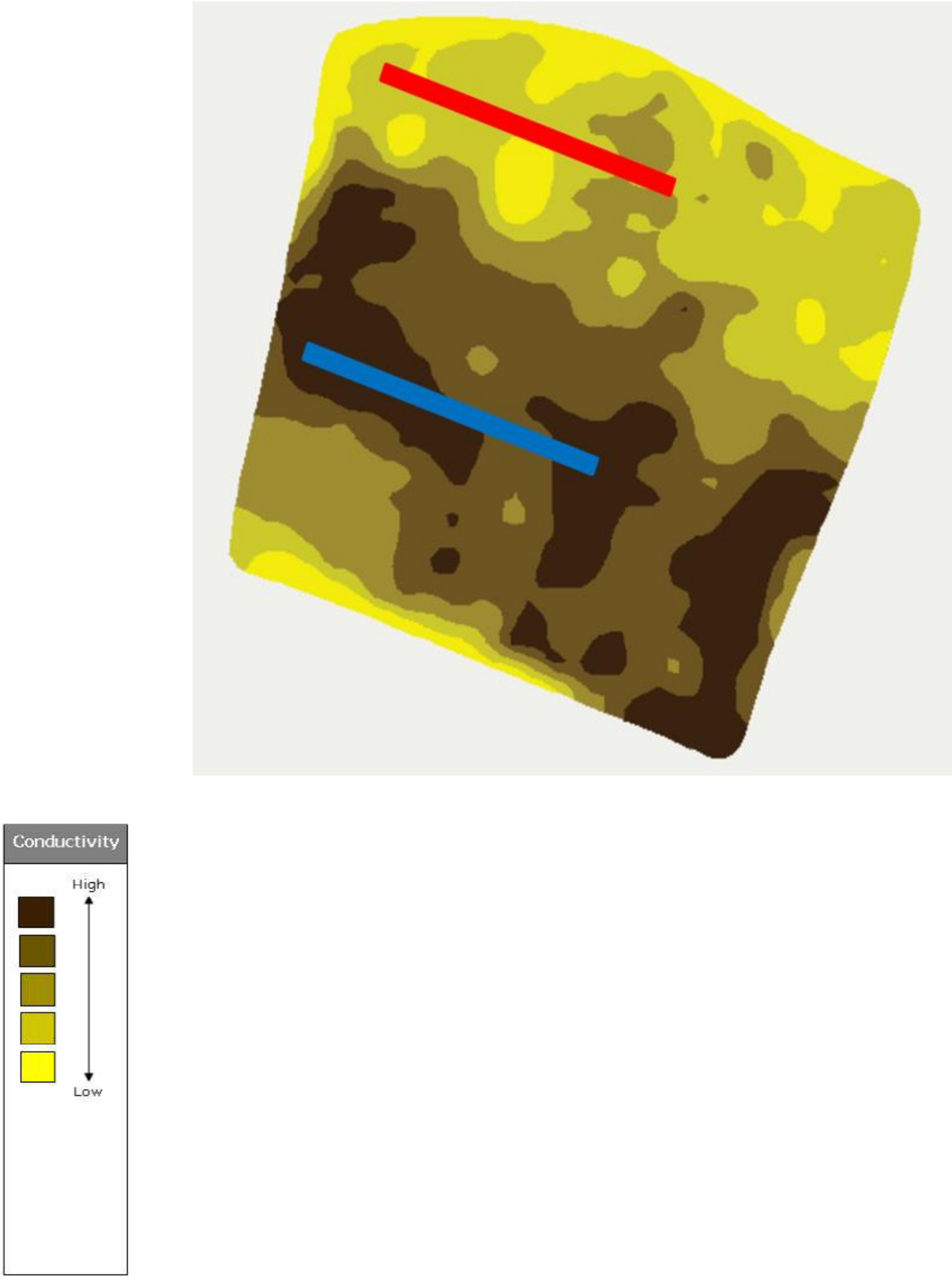


Figure 71. 2014: Location of Expt 2014-3 (blue area) shown on the EC map (0-40 cm) taken by SOYL in May 2012.

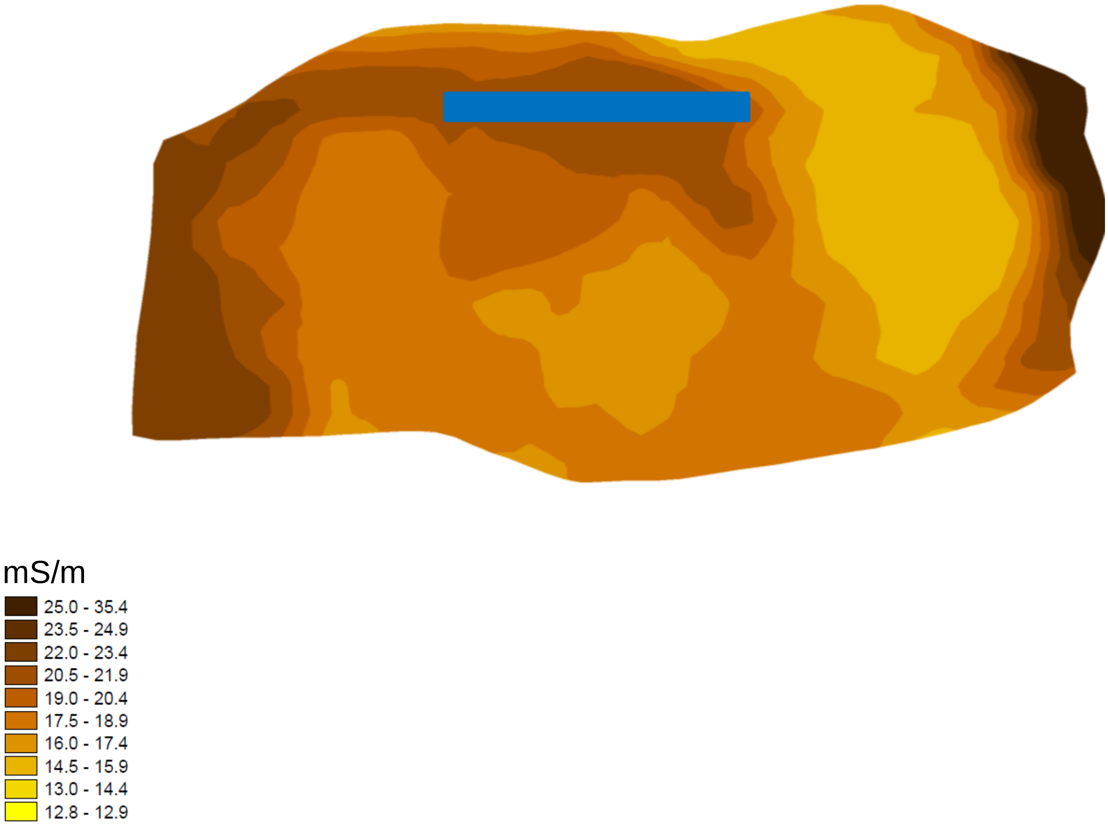


Figure 72. 2014: Location of Expt 2014-4 (blue area) shown on the EC map (0-4o cm depth) taken by SOYL in March 2014.

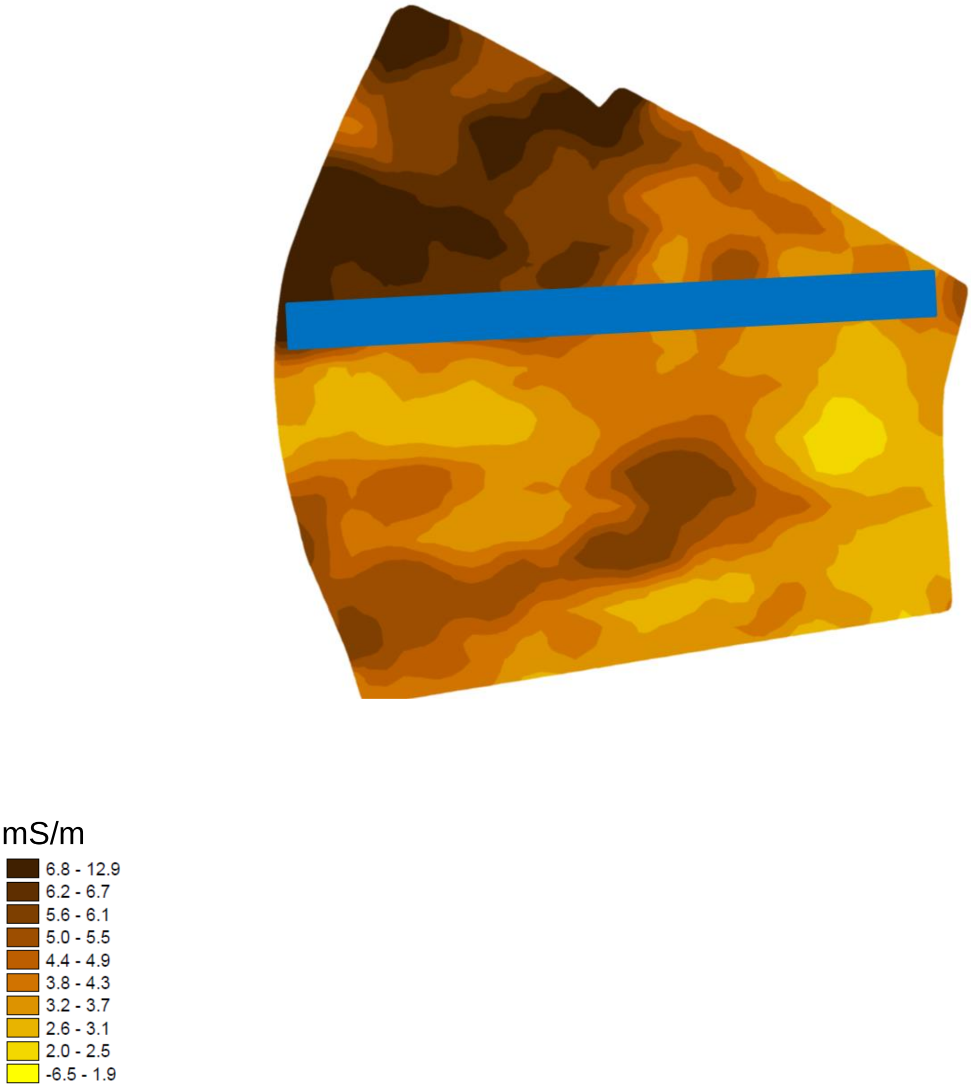


Figure 73. 2014: Location of Expt 2014-5 (blue area) shown on the EC map (0-40 cm) taken by SOYL in February 2014.

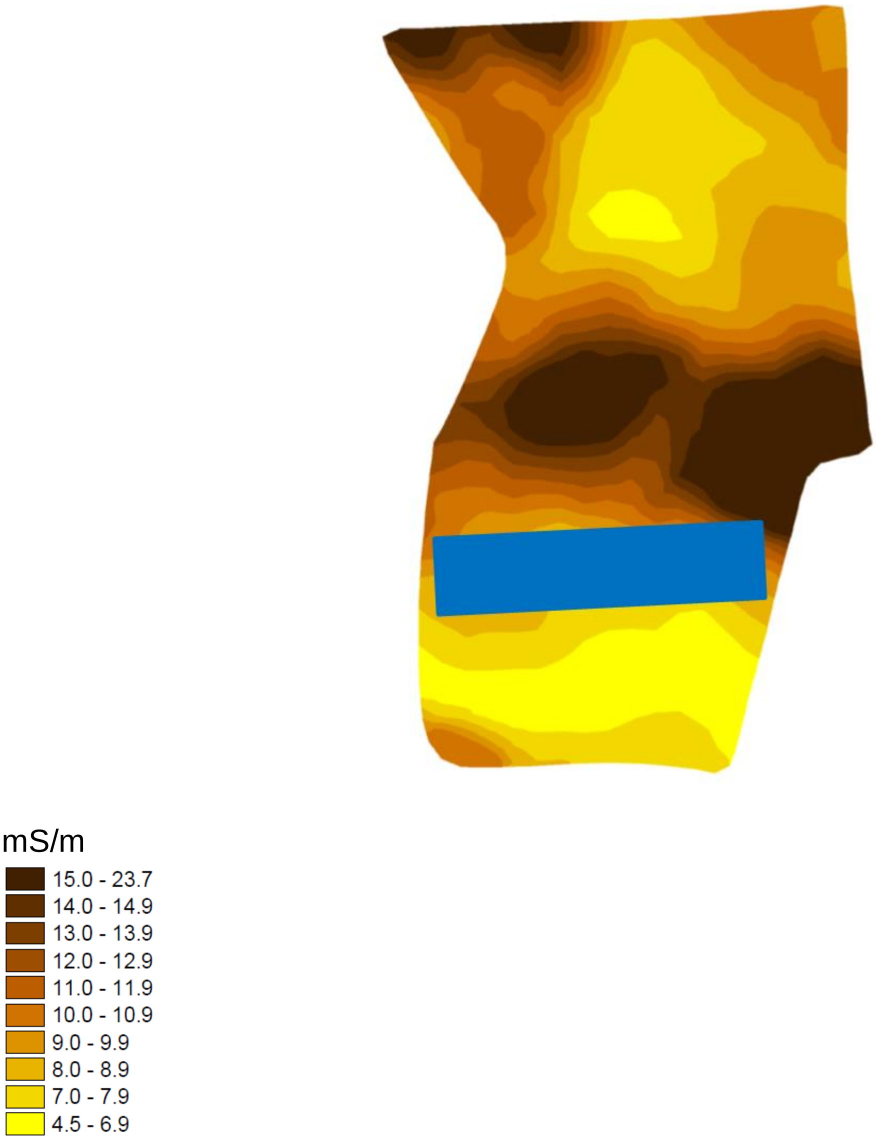


Figure 74. 2014: Location of Expt 2014-6 (blue area) shown on the EC map (0-40 cm depth) taken by SOYL in March 2014.

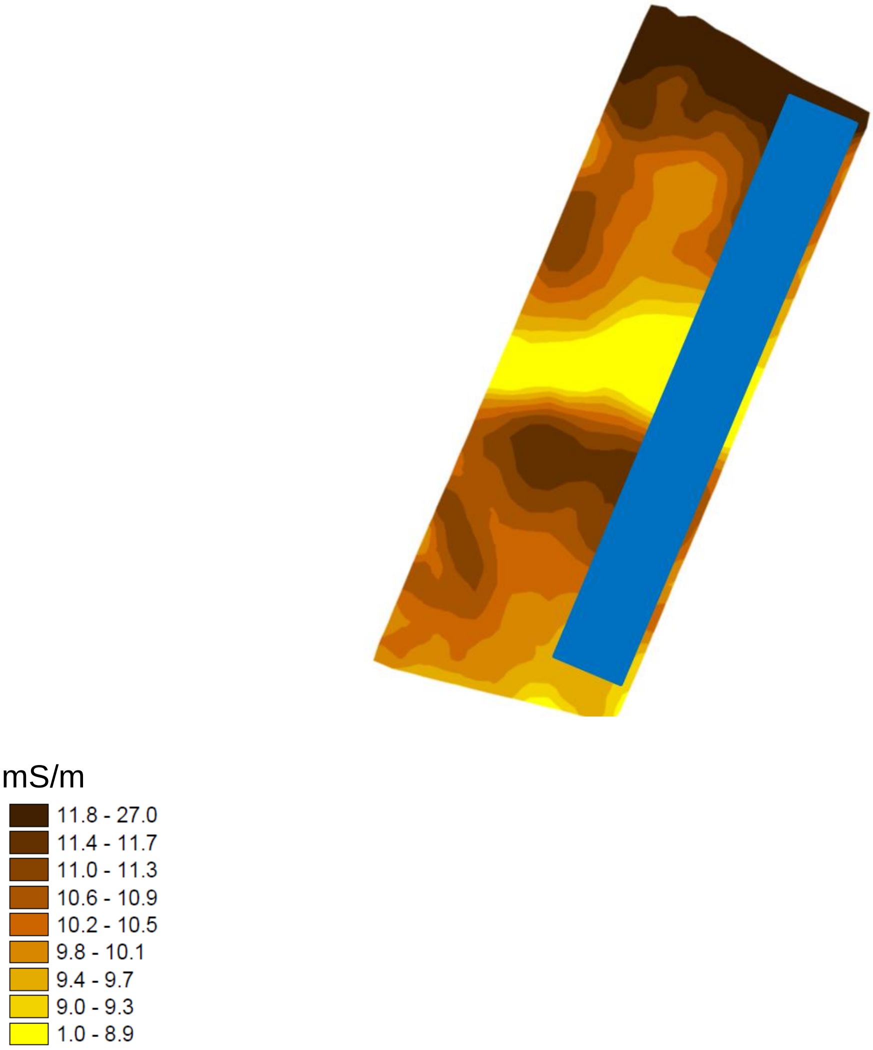


Figure 75. 2014: Location of Expt 2014-7 (blue area) shown on the EC map (0-40 cm depth) taken by SOYL in March 2014.

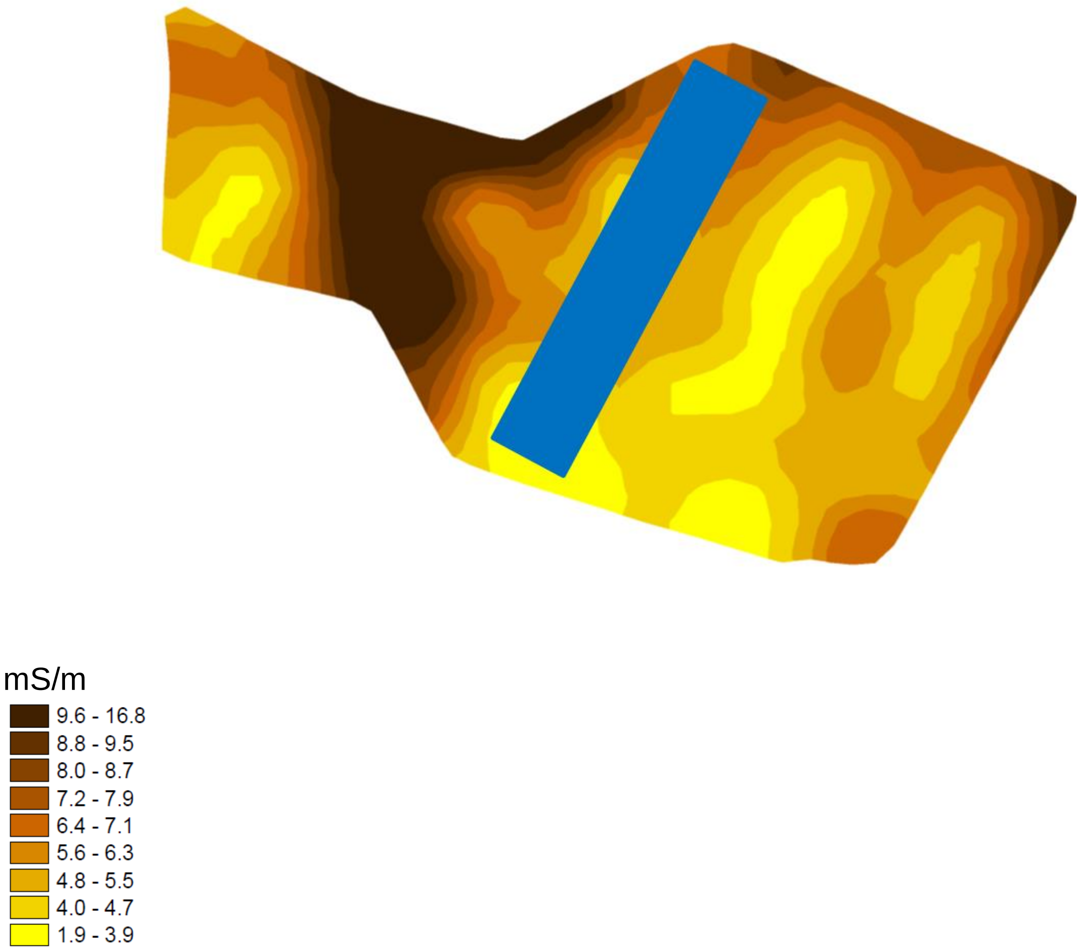


Figure 76. 2014: Location of Expt 2014-9: light area (red) and heavy area (blue) shown on the EC map (0-30 cm) taken by SoilQuest in December 2013.

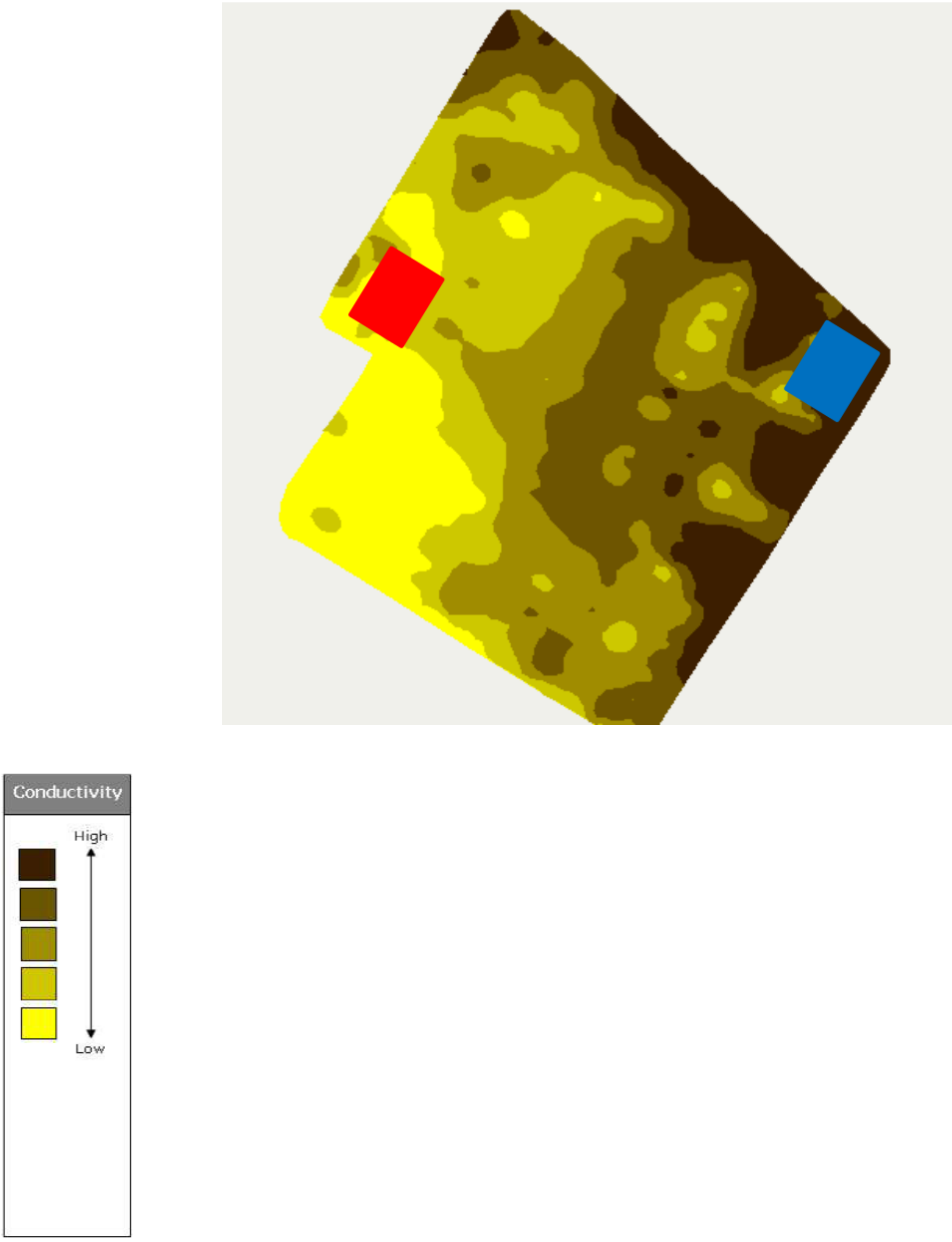


Figure 77. 2014: Location of Expt 2014-15 (blue area) shown on the EC map (0-40 cm) taken by SOYL in March 2014.

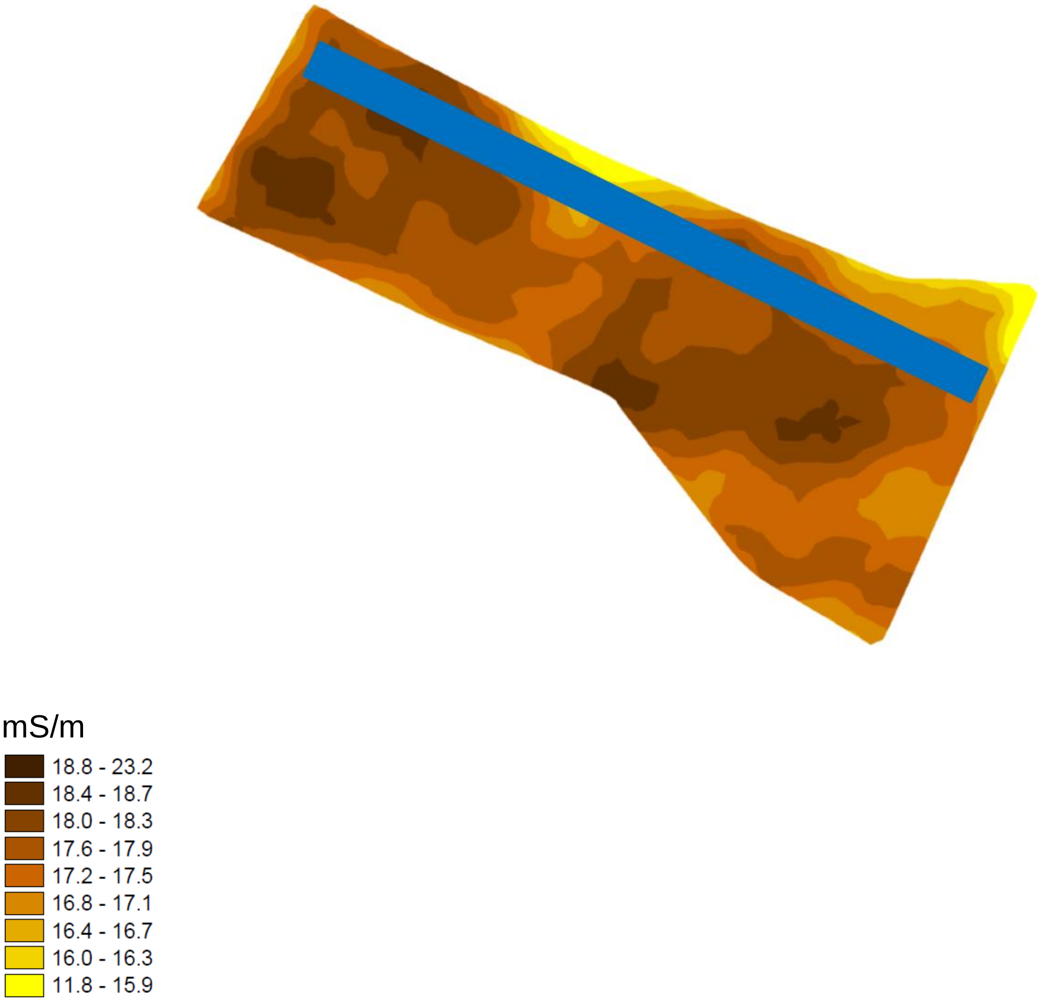


Figure 78. 2014: Location of Expt 2014-16 (blue area) shown on the EC map (0-40 cm depth) taken by SOYL in March 2014.