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 extension to project R459 were a) to identify optimal soil aggregate size distributions within ridges and b) increase soil structural stability in potato ridges in order to improve and guide cultivation practices in potatoes.

1.2. Methodology

Five replicated-block experiments were conducted on varying soil types in 2015. Through manipulation of different cultivation machinery and depth of cultivation, these were designed to:

- Quantify the effects of cultivation practices on bulk density, structural stability and aggregate size distribution.
- Quantify the effect of secondary cultivation machinery and depth of cultivation on tuber yield and quality.
- Produce a target of ‘best practice’ 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 the five additional experiments conducted in 2015 supported the findings of the main project, that yields from destoning at 22-28 cm (63.6 t/ha) were numerically greater (1.0 t/ha) than at the commercial depth (typically 27-36 cm), although these differences were not statistically significant in most individual experiments. There was again no evidence, however, that destoning shallower than commercial depth resulted in lower yield and a positive effect on yield from destoning shallower than the commercial depth was not necessarily anticipated at the start of the project but was observed in all five years of the project. Shallow destoning did not affect planting depth or the interval from planting to emergence, however there was more variation in planting depth and emergence in soil destoned deeper than commercial practice, particularly on heavier soils. There was also little effect of destoning depth on ground cover development.

Soil density in the ridge generally increased during the season as ridges consolidated owing to natural weathering and gravitational settling and through slumping from rainfall and irrigation. The reduction in porosity in sandy and silty soils during the season would reduce drainage rates during wet periods. Over-working soils typically resulted in more loose soil within the ridge at planting but by harvest this extra porosity had been lost and soils were similar density and porosity to those where destoning was shallower. The proportion of water stable aggregates (WSA) generally decreased only slightly between planting or emergence and harvest. However, in one experiment on soil composed of fine sand and silt, WSA increased significantly between planting and harvest. Cultivation regime had surprisingly little effect on WSA.

Overall, cultivation depth and intensity had little overall effect on the aggregate size distribution of soil within the ridge. Shallow, less intensive destoning (including widening the gaps in star separators or increasing the web pitch) often produced a visually cloddy surface which convinces growers that they may expect higher damage levels or be faced with more clod to deal with at harvest. However, measurements generally showed that internally within the bed, the size distribution of aggregates was similar at harvest irrespective of cultivation intensity and the amount of diesel consumed during cultivation. Differences in aggregate size distribution are often created at planting by varying the intensity of rotary and destoning cultivation, but these have largely disappeared by emergence and tuber initiation, the critical phase for having finer soil in the ridge to control common scab.

This does not negate the fact that there are large differences between soil types and sites but altering the operation of the cultivation tools at planting seems to be a relatively ineffective means of producing a ridge composed of the optimum range of aggregate sizes. Not surprisingly, the clay content of a soil was the most important factor determining aggregate size, but adding organic matter (OM) into the equation improved the prediction of mean aggregate size, in that soils with higher OM at a given clay content had smaller aggregates. It cannot be inferred from this project that adding OM to sandy soils would improve aggregate size, since this was not tested and most sandy soils had low OM content. Overall, clay soils (> 20 % clay) weathered to produce smaller clods by harvest and sandy soils (< 20 % clay) tended to aggregate slightly between planting and harvest. It was not possible to produce an optimal aggregate size distribution for ridges since there was a wide range of seedbeds that produced high yields of quality tubers. Fundamentally ridges should be composed of larger aggregates in sandy soils (8 mm rather than 6 mm) and contain *c*. 40 % of aggregates > 6 mm diameter rather than the 30 % currently achieved. Most clay soils are adequately fine (mean aggregate size 10 mm and 50-60 % of peds > 6 mm diameter) at planting. Throughout both projects, there were almost no examples of excessively cloddy seedbeds produced on heavy soils as most clod under such circumstances was removed to the furrow by destoners. There were certainly examples of overly-fine seedbeds produced on sandy soils, largely as a consequence of low OM, excessively deep destoning and finer-pitch webs (often deemed a necessity on stony soils).

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.   Importantly, tuber quality (common scab, cracking and greening) was not affected by destoning depth.

An overall improvement in rate of work of *c*. 33 % 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. Project R459 found that destoning at a depth of 27-28 cm was still 19 % faster than the current typical commercial rate. The most important feature of shallower destoning is the greater opportunity for soils to be cultivated closer to their optimum soil water content as progress can be faster during periods when soil is fit to cultivate without resorting to working soil when it is too wet. As found previously, there were small savings in fuel (£1-11/ha) from destoning beds shallower than current commercial depths and the cost (fuel and labour) saving per tonne of harvested tubers was generally small (*c*. 10-69 p/tonne). Shallower cultivation also reduces the wear on machinery and lowers labour and repairs costs. Increasing the pitch of the rear web on a destoner from 40 to 50 mm improved rate of work by 26 % and reduced labour and fuel costs by 21 %, equivalent to reducing the depth of destoning from 36 to 28 cm. There were few exceptions to this general observation, suggesting that growers currently cultivate soil unnecessarily deeply and intensively (star spacing or web pitch) and this is reducing their profit.

1.4. Practical recommendations

The main recommendations from Project R459 are shown with additional comments added from the extension project in the relevant areas studied.

- **Soil should not be cultivated deeper than is necessary to produce destoned beds *c*. 27-28 cm (clay soils 23-25 cm) in depth prior to planting.**
- **Destoning should not be deeper than 35 cm on sandy soils and deeper than 28 cm on heavy soils as this can result in reduced yields.**
- **Shallow destoning lowers labour costs through 20-40 % faster work rates.**
- **Destoning to produce beds at 27-28 cm gives greater opportunity for soils to be cultivated closer to their optimum soil water content.** This is a key area that can be exploited in wet springs (e.g. 2016) when planting can be delayed well into May, thereby incurring a yield loss owing to a truncated growing period. The ability to travel 30 % faster with shallower destoning could have a much larger effect on yield (e.g. 4-5 t/ha) than the average found from destoner depth experiments (1-2 t/ha).
- **Shallower destoning and bedforming on heavier soils results in fewer clods than deep destoning and can reduce the reliance on bedtilling.** 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.
- **Using wider pitch webs and larger gaps between stars on destoners will produce a coarser, more stable range of soil aggregates and prevent slumping.** The main issue is balancing stone and clod removal where both exist. Larger mean aggregate size is good for porosity and drainage and will not result in increased levels of damage at harvest. It is worth the downtime changing from a small pitch web for salad potatoes to a large pitch one for maincrop ware, or when changing soil types, as large improvements in soil structure and work rates can be achieved and fuel and labour costs can be reduced.
- **Where stone is the main issue to deal with, web-only machines are better.** There is a tendency with operators of star machines to close up the gaps between star rollers to avoid stones being pulled through into the seedbed but this leads to excessive grinding of soil at the front of the machine. As stars

wear, this increasingly becomes the situation as rollers are closed up as narrow as possible.

- **Seedbeds can be made appreciably coarser and shallower than current practice before any significantly increased risk of common scab or greening.** This is particularly the case on sandy soils where excessive destoning depth reduces an already small aggregate size to an overly-fine one. Whilst it is recognised that cultivation high clay content soils at the wrong water content can lead to excessively cloddy seedbeds, in general the experiments conducted on heavy soil in this project had good aggregate size distribution. Tuber quality (common scab, cracking and greening) is largely affected by destoning depth, aggressiveness of destoning or type of destoning machine but it should be noted that all experiments involving packing varieties were grown with irrigation scheduled using the NIAB CUF irrigation model. Previous AHDB Projects (e.g. R448, Stalham *et al.* 2015) have shown the importance of irrigation management for controlling scab. These two soils projects have shown that soil structure is less important in controlling common scab than may be thought.
- **Significant savings in fuel (e.g. £6-11/ha) can be made by destoning beds shallower than is currently being practiced.**
- **Producing beds as shallow as 25 cm will not affect planting depth or interval from planting to emergence**.
- **Destoner operators should receive training so that all beds are produced to similar depth which aids accurate planting (depth and spacing)**.
- **By gradually increasing the depth of destoning on heavier soils, operators are able to observe the sudden change in soil being placed in the furrow and this indicates that they are close to the critical depth for cultivation.**
- **Shallower destoning should be matched to shallower bedforming to maximize the benefits in terms of reduced fuel and labour costs and improved rate of work.**
- **Bedtilling should only be carried out where absolutely necessary and at the correct depth.** Too often, entire fields are bedtilled rather than spot treating areas of heavier soil and this wastes fuel and slows planting. Only the top 15-20 cm of the bed should be tilled rather than working the whole bed since the extra volume of soil involved with deep bedtilling results in ineffective

shattering of clods and also in fine aggregates being broken down further. Rates of work of destoners are only improved markedly by bedtilling when working soils deeply.

- **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.**

2. INTRODUCTION

The recently-completed three-year Potato Council-sponsored Project R459 was conducted to provide better quantitative relationships between the cultivatability, organic matter, depth of cultivation and wetness of soil and crop yield and quality. Soil mineral N and N uptake in crops grown in beds cultivated to contrasting depths was also measured to judge whether cultivation depth affected optimum rate of nitrogen fertilizer. An earlier Project (R405) showed that clod size within the ridge decreased during the season as the soil weathered and lost structure but there was limited degradation 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. Extended work in this area was conducted in R459, which showed that whilst ridge bulk density always increased from planting to harvest, particularly on sandy soils cultivated intensively, the magnitude and direction of any change in clod size was inconsistent. An extension to R459 was funded by AHDB Potatoes in 2015 to further study the effects of destoning and bedtilling on ridge soil structure, aggregate stability and crop yield and quality.

3. MATERIALS AND METHODS

In 2015, five experiments were conducted on sites in Cambridgeshire, Essex, Norfolk, and Staffordshire investigating the effect of bed depth and sieving (destoner) or rotary cultivator (bedtiller) aggressiveness on soil parameters, crop yield and quality (Table 1). All of these fields had historic or more recent surveys using electrical magnetic inductance (EMI) scanning by Dualem 1S undertaken by SOYL or Soil Essentials Ltd on a grid pattern of 12 m centres to two depths (30 and 90 cm). This type of EC 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 EMI images were used to select suitable areas in selected fields where there was little variation in apparent water content.

Table 1. List of experiments and basic details

Expt	Cultivated	Location	Soil texture	Treatments	Cultivation depths	Variety
2015-1	30 April	Cambridge, Cambridgeshire	Sandy loam	Machine x rainfall event	2	Maris Piper
2015-2	1 April	Hales, Norfolk	Loamy sand	Destoner depth	3	Jelly
2015-3	13 April	Aythorpe Roding, Essex	Clay	Destoner depth	3	Picasso
2015-4	24 April	Aylsham, Norfolk	Sandy silt loam	Destoner depth and web pitch	2	Maris Piper
2015-5	22 April	Colton, Staffordshire	Clay loam	Bedtiller and destoner depth	2	Innovator

Standard primary cultivations were used by growers prior to the secondary cultivation treatments being imposed. Operators were asked to load or work the cultivation machines with soil to similar levels and adjust the forward speed to maintain the soil load on the webs through different depth treatments. Following destoning or cultivation, the depth of the finished bed was measured prior to planting so that comparisons could be made with the intended depths. This was done by inserting a fibreglass flexicane with measurements marked on it into the bed to the cultivation layer. This was done in six positions (two left, two centre and two right) in each of two beds in the centre of each plot and the mean bed depth recorded. Plots were six to 12 rows wide and 20-30 m long in commercial fields to accommodate changes in soil load between different plots resulting from contrasting depths of destoning. The central four rows of each plot were used for plant and soil measurements.

3.1.1. Experiment 2015-1

Experiment 2015-1 investigated the effect of post-planting irrigation on soil properties of two contrasting tilths and was conducted in NIAB F33 field, Cambridge, Cambridgeshire. It was located on a sandy loam soil (59 % sand, 25 % silt and 16 % clay) with 2.8 % organic matter (OM) content (average readings for top 30 cm). The field was ploughed in autumn 2014 and the secondary cultivations were carried out on 30 April. The experiment was a factorial design of two cultivation treatments (Coarse , Fine) and three simulated intense rainfall events in the period following cultivation (at planting, at emergence, no rainfall). There were four replicates of the six treatment combinations arranged in a randomised block design.

Half the plots were pre-cultivated twice to a shallow depth (12 cm) using a 1.45 m wide L-blade Muritori MZ4 145 rotavator attached to a John Deere 4115 tractor with the aim of producing a very fine tilth prior to bedtilling. All plots were then roto-ridged using a Rumptstad bedtiller operating at 28 cm depth attached to a John Deere 6150R. Bedtilling was carried out at 3 km/h with the aim of producing a coarser structure than the surrounding experimental area. Those plots which were rotavated prior to bedtilling were designated the Fine treatment whilst those which were bedtilled only were designated Coarse. Unfortunately, the soil was in a very friable status at cultivation and the soil structural differences between Fine and Coarse cultivation regimes were smaller than anticipated.

The three simulated rainfall treatments were unirrigated prior to June (None); irrigated on the day of planting (Planting) and irrigated at 50 % crop emergence on 1 June (Emergence). Irrigation was applied using a Househam Air Ride 2000 24 m self-propelled sprayer with high-flow 135° cone nozzles. The outer section of the three-section boom was used to apply 15 mm of water at a rate of 15.25 mm/min over a 0.5 m swath of the plot and then the sprayer was moved forward another 0.5 m (eight moves in total to irrigate each 4 m plot).

Planting was carried out on 1 May by hand-dibbing 30-40 mm Maris Piper seed at a spacing of 30 cm in 75 cm rows into the re-formed ridges. The ridges were raked post-planting to reproduce the original shape. Plots were 4 m long and six rows wide and pathways 5 m wide were left between blocks to facilitate turning of tractors during cultivation.

Soil samples for bulk density, aggregate size distribution and wet sieving soil stability were taken at planting, 15 May, 12 June and 5 October. A hand-dug final harvest of 2.25 m^2 was conducted on 5 October.

3.1.2. Experiment 2015-2

Experiment 2015-2 was conducted in Workhouse field, Hales, Norfolk farmed by Greenvale AP Ltd and was located on a loamy sand soil (81 % sand, 12 % silt and 7 % clay) with 1.6 % OM content. It was bedformed and destoned on 1 April and planted on the same day using 40-50 mm Jelly seed at a within-row spacing of 36 cm in 96.5 cm rows. It was destoned using a Grimme CS170 with 28 mm web towed by a New Holland T6080 tractor. The three destoning depth treatments were 25, 37 and 45 cm. There were four replicates laid out in a randomised block design. Ridge soil bulk densities were taken on 1 April, 26 May and 2 September. A hand-dug final harvest of 2.90 m^2 was conducted on 2 September.

3.1.3. Experiment 2015-3

Experiment 2015-3 was conducted in Waterloo field, Aythorpe Roding, Essex farmed by Stevenson Bros. It was located on a clay soil (22 % sand, 38 % silt and 40 % clay) with 4.4 % OM content. The experimental area was re-bedformed from over-wintered beds on 12 April and destoned and planted on 13 April using 45-55 mm Picasso seed at a within-row spacing of 29 cm in 91 cm rows. It was destoned using a Pearson Megastar Gen-2 towed by a John Deere 6930 tractor. The three destoning depth treatments were 22, 27 and 33 cm. There were four replicates laid out in a randomised block design. Ridge soil bulk densities were taken on 13 April, 21 May and 15 September. A hand-dug final harvest of 2.74 m^2 was taken on 15 September.

3.1.4. Experiment 2015-4

Experiment 2015-4 was conducted in Eldens field, Tuttington, Norfolk farmed by Stratton Streles Estate. It was located on a sandy silt loam soil (45 % sand, 39 % silt and 16 % clay) with 2.4 % OM content. Bedforming and destoning was carried out on 24 April and two Pearson Unistar destoners towed by John Deere 6930 and New Holland T7.235 tractors were used for the destoning depth x web pitch factorial comparison. The standard commercial-practice was to have a 40 mm rear web. The second machine had the rear web changed to one with a 50 mm pitch. The two destoning depth treatments were 28 and 36 cm. There were four replicates of each of the four treatment combinations laid out in a randomised block design. The experiment was planted on the same day as destoning using 25-35 mm Maris Piper seed at a within-row spacing of 34 cm in 102 cm rows. Ridge soil bulk densities were taken on 24 April, 21 May and 22 September. A hand-dug final harvest of 3.05 m^2 was taken on 22 September.

3.1.5. Experiment 2015-5

Experiment 2015-5 was conducted at the AHDB SPot Farm demonstration site in Colton, Staffordshire farmed by WB Daw & Sons. It was located on a clay loam soil (49 % sand, 26 % silt and 25 % clay) with 3.1 % OM content. The experiment was a randomised block design of two treatments: bedtill and destone shallow (Coarse) or deep (Fine) with six replicates. In the two weeks prior to bedforming and bedtilling, the field was ploughed to 35 cm depth. The bedtilling treatments were carried out on 22 April using a Grimme RT6000 Rototiller bedtiller towed by a Fendt 936 Vario, the target being to produce two very contrasting soil aggregate size distributions for the seedbed. To achieve this, the bedtiller was run deep and very slowly to produce a fine seedbed and run *c*. twice as fast as the commercial rate and very shallow to produce a coarse seedbed. The shallow bedtilling treatment was carried out at 52 % on the tractor's hydraulic link arms and the deep at 32 %. These resulted in tilled bed depths of 40 and 67 cm, respectively. The destoning was carried out using a Grimme CS150 towed by a John Deere 6150R. In the shallow bed-tilled plots, the depth of the finished beds post-destoning was 28 cm and in the deep-tilled beds 38 cm. Planting was carried out on 23 April with 45-55 mm Innovator seed at a spacing of 32 cm in 91 cm rows. Plots were 30 m long and six rows wide. Soil samples for bulk density, aggregate size distribution and wet sieving soil stability were taken on 23 April and 10 September. A hand-dug final harvest of 2.74 m^2 was conducted on 10 September.

3.2. Speed and fuel measurements

Spot rates of forward speed and fuel consumption were measured using each 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. The fuel and rate of work were converted into monetary value using the price of red diesel as 52.5 p/l and skilled labour at £16.25/h (April 2015).

3.3. Soil and plant measurements

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 at final harvest. A final harvest from two rows in Expt 2015-1 and a single row in all other experiments was taken (see individual experiments for dates and harvest area). 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]). In Expts 2015-1 to 2015-4 (located in fields where the produce was destined for packing), 50 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 from all experiments were also assessed for type, incidence and severity of tuber cracking, greening and other growth defects at final harvest. All experiments were irrigated and were scheduled according to the NIAB CUF irrigation model.

Ridge bulk density and ped size distribution was measured by grading a large-volume (2.0 l) soil sample taken at planting and again at final harvest. In some experiments, there were intermediate dates of sampling. After removing 1 cm of soil from the apex of the ridge, a lidded 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 with a spade. The soil was transferred to a plastic bag, 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.

Wet soil stability was measured on sub-samples extracted from the oven-dried soil from the ridge bulk density cores using an Eijkelkamp Wet Sieving Apparatus. To determine the stability, sieves (with 0.25 or 2 mm mesh screen) were loaded with 4 g of soil aggregates from the ridge. The samples were pre-moistened using a plant spray 5 min before submerging them. These sieves were then moved up and down by the machine into cans 80 % filled with water at a frequency of 34 cycles/min for 3 min, the principal being that unstable aggregates would break apart and pass through the sieve and be collected in the water-filled can underneath the sieve. All soil remaining on the sieve was washed into small aluminium trays and dried at 105 °C for 24 h. The dried weight of soil represented the stable aggregate fraction. After four samples had been processed, the water in the cans was replaced with fresh water. Two replicate samples per plot were tested owing to the small mass of soil tested. The water stable aggregate (WSA) data are presented on a proportional scale with 1 = all soil remaining on sieve.

Statistical analysis was carried out using Genstat® 16th Edition.

4. RESULTS

4.1. Speed and fuel consumption

In Expt 2015-2, increasing the depth of destoning slowed rate of work and increased fuel usage. The rear web on the destoner was 28 mm (for destoning salad crops despite the crop being destined for 45-70 mm tubers) and progress was slow for such a coarse-textured soil. Destoning at 25 cm reduced the fuel usage by 35 %, improved rate of work by 55 % and reduced fuel and labour costs per tonne of ware produced by 43 % *c.f.* the Commercial depth (Table 2).

In Expt 2015-3, increasing the depth of destoning slowed rate of work and increased fuel usage but by a smaller proportion than in Expt 2. Destoning at 22 cm reduced fuel usage by 19 %, improved rate of work by 28 % and reduced fuel and labour costs per tonne by 18 % *c.f.* the Commercial depth (Table 2).

Table 2. Expts 2015-2 and 2015-3: effect of destoning depth on rate of work, fuel consumption and fuel and labour costs. S.E. based on 6 D.F.

Expt	Destoner depth (cm)	Rate (ha/h)	Fuel (l/ha)	Fuel (£/ha)	Labour (£/ha)	Fuel and labour (£/t)
2015-2	Shallow (25)	0.37	29.0	19.75	38.74	0.91
	Commercial (37)	0.24	44.7	30.41	61.30	1.60
	Deep (45)	0.14	61.5	41.83	101.85	2.52
	S.E.	0.018	2.21	1.502	3.80	0.153
2015-3	Shallow (22)	0.69	12.1	6.38	25.1	0.47
	Commercial (27)	0.54	15.0	7.85	31.5	0.57
	Deep (33)	0.33	23.6	12.40	50.0	0.98
	S.E.	0.068	1.55	0.815	3.35	0.059

In Expt 2015-4, increasing the depth of destoning and using the commercially-sized rear web rather than 50 mm web slowed rate of work and increased fuel usage. Destoning at 28 cm reduced the fuel usage by 19 %, improved rate of work by 21 % and reduced fuel and labour costs per tonne of ware produced by 28 % *c.f.* the Commercial depth (Table 3). Likewise, increasing the pitch of the rear web increased rate of work by 26 % and reduced fuel and labour costs by 21 % (Table 3).

Table 3. **Expt 2015-4: effect of destoning depth and rear web pitch on rate of work, fuel consumption and fuel and labour costs. S.E. based on 9 D.F.**

Destoner depth (cm)	Rear web pitch (mm)	Rate (ha/h)	Fuel (l/ha)	Fuel (£/ha)	Labour (£/ha)	Fuel and labour (£/t)
Shallow (28)	40	0.62	22.2	11.66	26.35	0.49
	50	0.78	18.4	9.66	20.81	0.38
Commercial (36)	40	0.51	27.7	14.54	32.47	0.68
	50	0.64	22.7	11.92	25.36	0.54
S.E.		0.020	0.54	0.28	0.97	0.020

Producing the Coarse, shallow seedbed in Expt 2015-5 reduced fuel usage by 69 %, improved rate of work of the bedtiller by 75 % and the destoner by 21 % and reduced fuel and labour costs per tonne by 58 % compared with the Fine, deep seedbed (Table 4).

Table 4. **Expt 2015-5: effect of seedbed tilth cultivation regime on rates of work and fuel consumption. S.E. based on 5 D.F.**

Seedbed tilth	Bedtiller rate (ha/h)	Bedtiller fuel (l/ha)	Destoner rate (ha/h)	Destoner fuel (l/ha)	Total fuel (£/ha)	Fuel and labour (£/ha)	Fuel and labour (£/t)
Coarse	1.76	20.8	0.61	24.8	23.95	60.00	1.15
Fine	0.44	111.7	0.48	34.2	76.61	147.89	2.75
S.E.	0.000	1.69	0.016	0.351	0.925	1.610	0.099

4.2. Planting depth, emergence and ground cover

As an overall summary, the intended target commercial planting depth (typically 15 cm) was achieved for all depths of destoning in all experiments, even for very shallow destoning. As might be expected from a generally consistent planting depth, the interval from planting to emergence was not affected by cultivation treatments in most experiments.

In Expt 2015-1, crops planted in cloddy seedbeds were slightly (i.e. 1 day) slower to reach first emergence (27.1 ± 0.15 days after planting) and 50 % emergence (30.6 ± 0.21 days after emergence) than those planting in fine seedbeds (26.6 and 29.9 days, respectively). Almost all plots had one plant in the harvest area (i.e. 96 % emergence) that had failed to emerge by 45 days after emergence. Planting depth was the same across all treatments (13.0 ± 0.39 cm). There was no effect of tilth or simulated rainfall treatments and all treatments reached full ground cover *c*. 44 days after emergence and only commenced senescence in the middle of September, all plots retaining *c*. 50 % ground cover at harvest.

In Expt 2015-2, 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. Planting depth was the same for all destoning depths (15.3 ± 0.25 cm). Ground cover development was identical for all destoning depths until recordings were stopped 3 weeks after full canopy cover had been achieved.

In Expt 2015-3, 50 % emergence was 3 days earlier in the shallowest destoning treatment (44 ± 0.56 days after planting) than in the Commercial and Deep treatments. Planting depth was deeper where destoning was carried out at 22 cm (14.2 ± 0.25 cm) than at 27 or 33 cm (13.2 cm), yet emergence was more rapid, probably owing to the dry conditions in the ridge where soil was worked more intensively. Complete plant emergence was later where the soil was destoned deeper than the Commercial depth. Ground cover development was slightly more advanced for the shallowest destoning depth until *c*. 20 days after emergence but within a further 7 days all treatments had similar ground covers until recordings were stopped 2 weeks after full canopy cover had been achieved.

In Expt 2015-4, 50 % emergence was 32 days after planting for both destoning depths and web pitches and there were similar numbers of plants emerged in all strips used to measure emergence, irrespective of cultivation regime. Planting was much deeper in this experiment than in the other experiments, but was the same for all destoner combinations (19.1 ± 0.54 cm). Ground cover development was not recorded in this experiment.

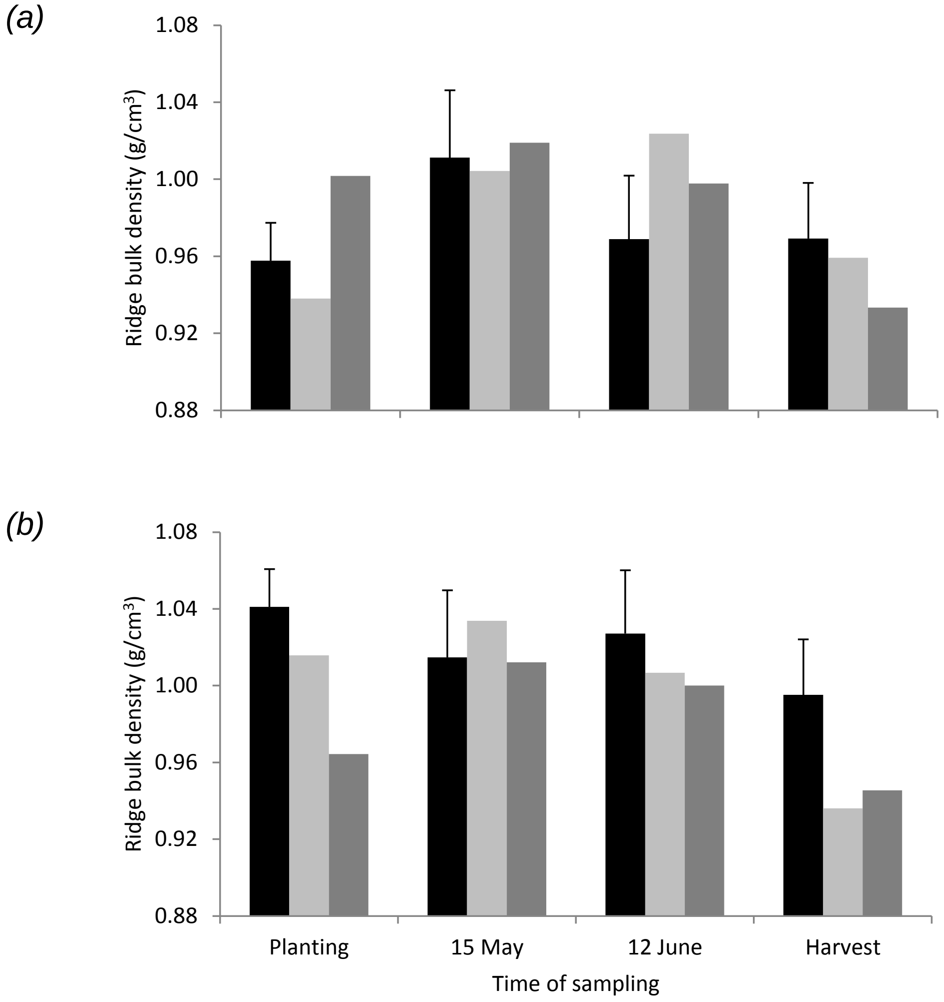
In Expt 2015-5, 50 % emergence was 36 days after planting for both Coarse and Fine treatments and although emergence was protracted (12-days from first to complete emergence), there were similar final numbers of plants emerged, irrespective of depth and intensity of cultivation. Planting depth was the same for both types of seedbed (14.9 ± 0.75 cm). Ground cover development was identical for both cultivation regimes until recordings were stopped when full canopy cover had been achieved.

4.3. Soil properties

4.3.1. Ridge density

In Expt 2015-1, there were no differences between treatments in ridge soil density at planting, emergence, tuber initiation or harvest or the change in density between planting and harvest (Figure 1). In general, ridge density decreased slightly from 0.99 g/cm^3 at planting to 0.95 g/cm^3 at harvest but increased slightly between planting and emergence (1.01 g/cm^3). The Coarse treatment tended to have a slightly higher ridge density throughout the season than the Fine (Figure 1).

Figure 1. Expt 2015-1: effect of tilth type, simulated rainfall events and time of sampling on ridge density. *(a)* Fine tilth; *(b)* Coarse tilth. Simulated rainfall: None, ■; Planting, ░; Emergence, ▓. Error bars based on 15 D.F.



In Expt 2015-2, ridge density at planting was lower in Deep destoning than in Shallow or Commercial but by emergence all destoning treatments had a similar density (Table 5). There was a large increase in density between emergence and harvest but there remained no effect of destoning depth (Table 5).

In Expt 2015-3, ridge density was very low at planting and had increased by emergence but destoning depth had no significant effect at either sampling (Table 5). By harvest, ridge density had increased further and whilst the two shallowest destoning depths had a similar density, deep destoning resulted in a higher ridge density (Table 5).

Table 5. **Expts 2015-2 and 2015-3: effect of destoning depth and time of sampling on ridge density (g/cm^3). S.E. based on 6 D.F.**

Expt	Destoner depth (cm)	Planting	Emergence	Harvest
2015-2	Shallow (25)	1.12	1.12	1.29
	Commercial (37)	1.11	1.10	1.30
	Deep (45)	1.06	1.11	1.30
	S.E.	0.018	0.031	0.025
2015-3	Shallow (22)	0.77	0.83	0.88
	Commercial (27)	0.73	0.85	0.86
	Deep (33)	0.73	0.82	0.94
	S.E.	0.013	0.029	0.031

In Expt 2015-4, there was no effect of web pitch or destoning depth on ridge density which was lowest at planting (1.01 ± 0.015 g/cm^3) but density did not change between emergence (1.04 ± 0.013 g/cm^3) and harvest (1.04 ± 0.048 g/cm^3).

In Expt 2015-5, despite a very large difference in secondary cultivation intensity between treatments, there was no significant effect of cultivation on ridge density at planting or harvest. In contrast to most experiments in this study, ridge density decreased from 1.09 ± 0.027 g/cm^3 at planting to 0.97 ± 0.026 g/cm^3 at harvest.

4.3.2. Aggregate size distribution

The most important period to have a fine tilth, i.e. small mean aggregate size distribution, would be expected to be around the time of tuber initiation, since this should contribute to control of common scab with irrigation. Most sites were sampled at emergence, *c*. 2 weeks prior to tuber initiation, and therefore this would be a good indicator of the tilth prior to commencing irrigation for scab control.

In Expt 2015-1, there was no effect of any treatment on the proportion of soil made up of aggregates > 25 mm diameter but there were consistent differences between Fine and Coarse tilth in the distribution of aggregates < 20 mm diameter. Across all sample dates, there was a greater proportion of ridge soil with aggregates in the 10-15, 6-10 and 2-6 mm grades in Fine tilth but Coarse tilth had consistently more soil in the < 2 mm grade. This is somewhat surprising given that the intention of pre-rotavating prior to rototilling was to create a finer tilth. An example of the distribution of aggregates at emergence is given in Figure 2. At this stage in the season, the Fine treatment had a greater mean ped size (Table 2), more aggregates > 6 mm and fewer peds < 2 mm than the Coarse.

Figure 2. Expt 2015-1: effect of tilth type, simulated rainfall events on aggregate size distribution at emergence. *(a)* Fine tilth; *(b)* Coarse tilth. Simulated rainfall: None, ■; Planting, ■; Emergence, ■. Error bars based on 15 D.F.

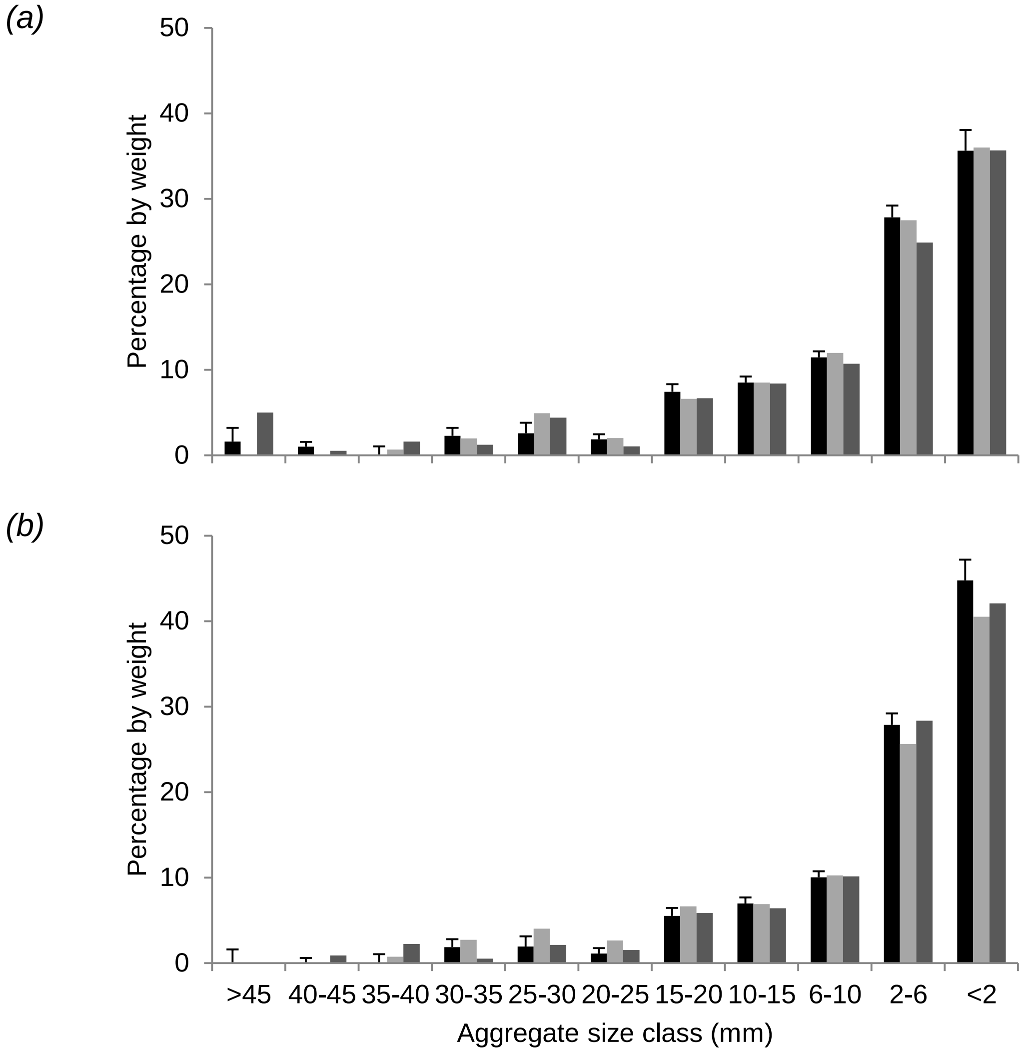


Table 6. Expt 2015-1: effect of tilth type, simulated rainfall events and date of sampling on mean ped size (mm) at emergence. S.E. based on 15 D.F.

Tilth	Simulated rainfall event	Planting	Emergence	Tuber initiation	Harvest
Coarse	None	7.8	5.6	5.7	6.0
	Planting	6.5	7.1	5.4	6.4
	Emergence	7.1	6.5	5.8	6.2
Fine	None	6.3	7.8	6.0	5.9
	Planting	7.3	7.3	6.6	6.5
	Emergence	6.2	7.9	6.2	6.6
S.E.		0.53	0.95	0.73	0.56

In Expt 2015-2, mean aggregate size was not affected by destoning depth but aggregate size tended to decrease between planting and emergence (Table 7). Soil was sampled at harvest when the ridges were very wet and the drying caused significant aggregation of soil producing the very high mean aggregate size in Table 7.

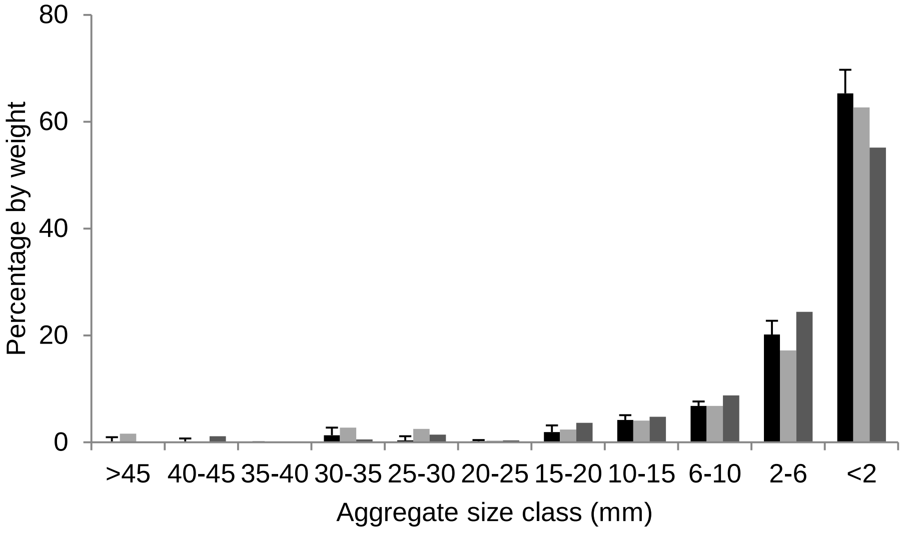
An example of the aggregate size distribution for Expt 2 at emergence is shown in Figure 3. There was no effect of destoning depth on aggregate size distribution at this crucial time.

Table 7. Expts 2015-2 and 2015-3: effect of destoner depth on mean aggregate size in the ridge. S.E. based on 6 D.F.

Expt	Destoner depth (cm)	Planting	Emergence	Harvest
2015-2	Shallow (25)	6.6	3.4	13.3†
	Commercial (37)	5.2	5.0	13.4†
	Deep (45)	6.9	4.6	13.4†
	S.E.	1.48	1.08	3.44
2015-3	Shallow (22)	12.3	8.1	7.6
	Commercial (27)	12.2	8.8	7.4
	Deep (33)	15.0	9.3	8.2
	S.E.	0.56	0.44	0.28

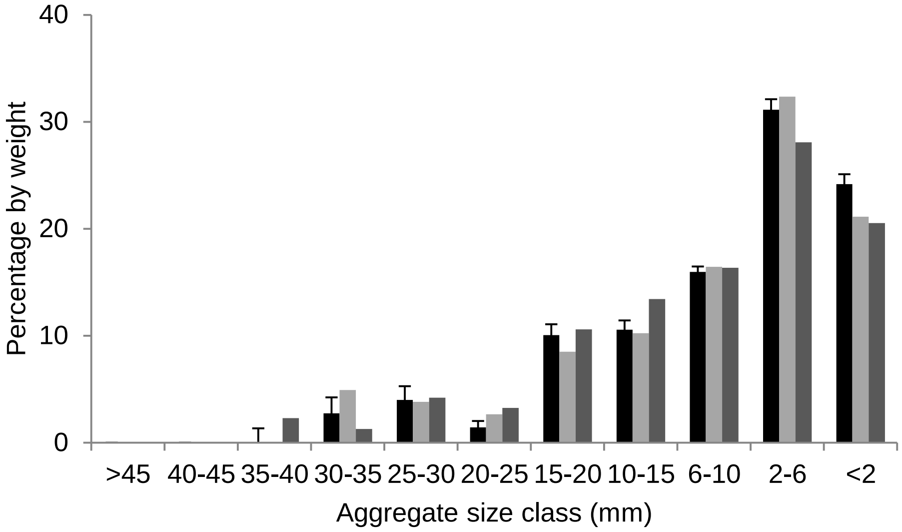
†Large mean aggregate size due to soil clumping during drying leading to large proportion of peds >45 mm.

Figure 3. Expt 2015-2: effect of destoner depth on aggregate size distribution in the ridge at emergence. Shallow, ■; Commercial, ■; Deep, ■. Error bars based on 15 D.F.



In Expt 2015-3, mean aggregate size was increased at planting by Deep destoning (Table 7), largely as a consequence of fewer peds < 2 mm in Deep versus Shallow or Commercial. Aggregate size decreased considerably between planting and emergence and between emergence and harvest, with most of the change occurring between planting and emergence (Table 7). An example of the aggregate size distribution at emergence for Expt 3 is shown in (Figure 4). Deep destoning resulted in more aggregates > 6 mm than Shallow or Commercial destoning depths.

Figure 4. Expt 2015-3: effect of destoner depth on aggregate size distribution in the ridge at emergence. Shallow, ■; Commercial, ░; Deep, ▓. Error bars based on 15 D.F.

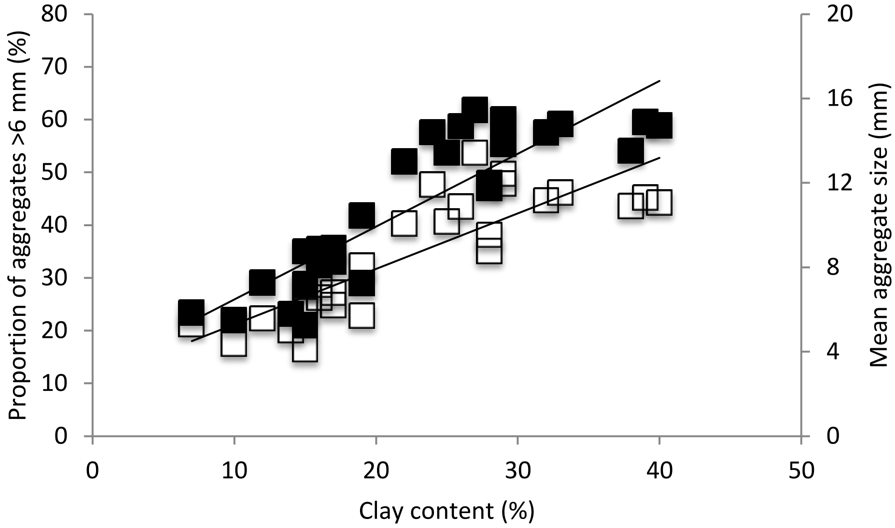


In Expt 2015-4, the mean aggregate size at planting was significantly larger for the 50 mm web (8.1 mm) than the 40 mm web (5.8 ± 0.62) but this difference had decreased by emergence (7.9 mm and 6.9 ± 0.30 mm, respectively). The proportion of aggregates > 6 mm was greater at planting for the 50 mm web (38.3 ± 2.03 %) than the 40 mm web (30.1 %) but the difference had narrowed by emergence (38.5 % and 34.8 ± 1.09 %, respectively). The soil was too wet at harvest to gain useful information on aggregate grading as the soil dried in a large lump.

In Expt 2015-5, mean aggregate size at planting was much larger in the Coarse regime (15.4 ± 0.56 mm) than Fine (9.2 mm) but the difference, whilst still significant, was much smaller at harvest (Coarse 8.8 mm, Fine 7.2 ± 0.41 mm). The proportion of aggregates > 6 mm was much larger at planting for Coarse (74.2 ± 1.22 %) than Fine (50.0 %) and still significantly different by harvest (49.7 and 40.6 ± 1.18 %, respectively).

Examining the soil grading data from all experiments in 2012-2015, the clay content of the soil was the over-riding factor in mean aggregate size and the proportion of aggregates > 6 mm, with higher clay content leading to larger aggregates. A close correlation was observed between the clay content and both mean aggregate size and the proportion of aggregates > 6 mm (Figure 5). In both projects, soil OM was only loosely related to clay content, with high clay content soils generally having greater OM content than sandy soils, but there was a range of OM content in the soils tested owing to previous cropping and practice of manuring. There were several sandy clay loam soils (clay content 24-29 %) with a range in OM from 1.5 to 3.5 %, whilst the complete range in OM of soils where soil grading took place was 1.5 to 4.4 %. Performing a multi-variate analysis using Genstat®, clay content was the most important factor determining aggregate size and adding OM into the equation had a significant additive effect in predicting the aggregate size. The overall relationship between mean aggregate size and clay (C) and OM content was $y = 0.382C - 1.86OM + 4.44$ (% variance accounted for 83.1), whilst the overall relationship between the proportion of aggregates > 6 mm and clay and OM content was $y = 1.87C - 7.64OM + 19.3$ (% variance accounted for 84.7). This suggests that that OM had an overall effect in reducing aggregate size but it does not imply that adding OM to sandy soils would necessarily improve aggregate size. The clay soils shown in Figure 5 (three points at 38-40 % clay) had lower than expected aggregate size, possibly as a consequence of having high OM content (3.9-4.4 %), although all three of these sites were bedtilled prior to destoning.

Figure 5. Relationship between clay content and the proportion of aggregates > 6 mm and mean aggregate size in all experiments from Project R459 and the extension project. Linear relationships: proportion of aggregates > 6 mm, ■, $y = 1.38x + 12.1$, $R^2 = 0.78$; mean aggregate size, □, $y = 0.263x + 2.67$, $R^2 = 0.72$.



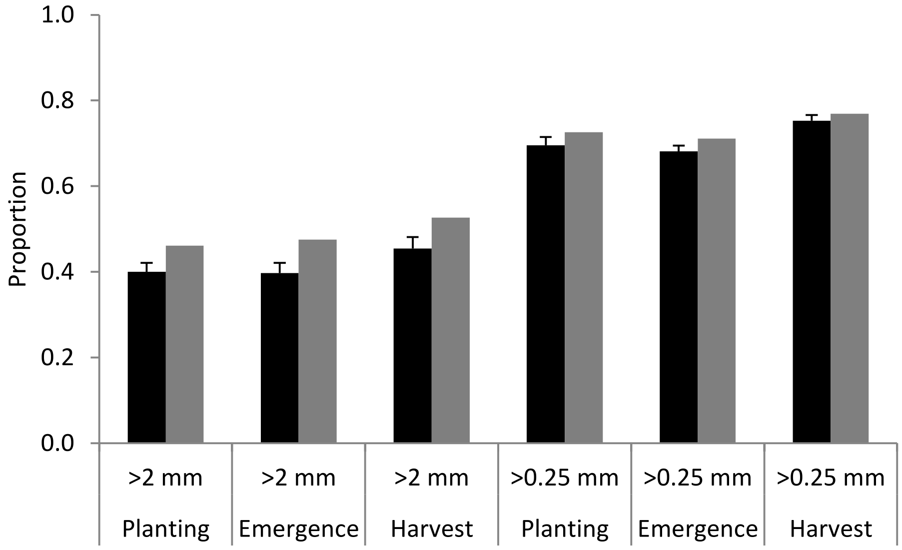
4.3.3. Aggregate stability

The wet aggregate stability is determined on the principle that unstable aggregates will break down more easily than stable aggregates when immersed into water.

In Expt 2015-1, for samples taken at planting, the Fine tilth treatment had more WSA > 2 mm than the Coarse but there was no effect of tilth on WSA > 0.25 mm (Figure 6). Simulated rainfall at planting increased the proportion of WSA > 0.25 mm (0.76) compared with rainfall at emergence (0.70 ± 0.019). At emergence, WSA at both 2 and 0.25 mm were increased in Fine tilth compared to Coarse (Figure 6). There was no effect of simulated rainfall treatments on WSA at emergence. By harvest, the Fine tilth still had more WSA > 2 mm than Coarse but there was no effect on WSA > 0.25 mm (Figure 6). There was no effect of simulated rainfall on WSA on soil samples taken at harvest.

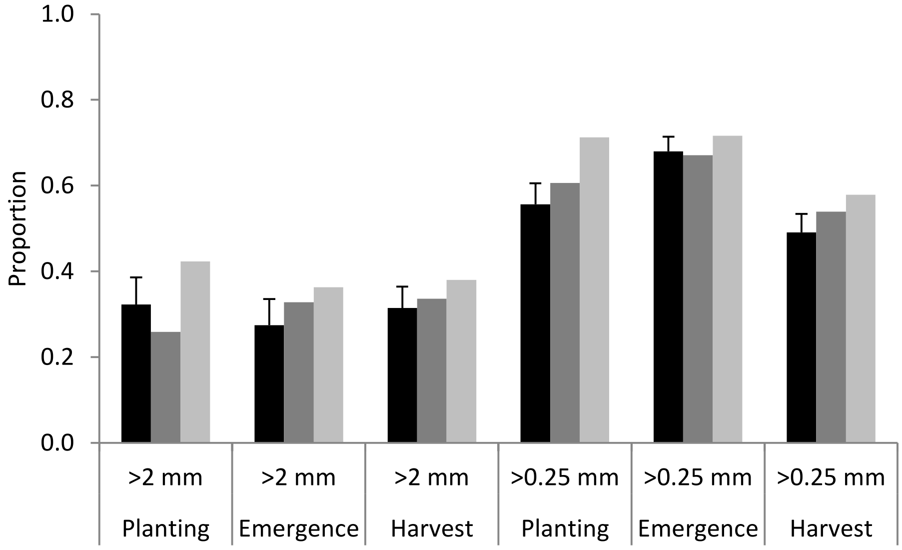
Between planting and harvest, there was an overall reduction (-0.06) in WSA > 2 mm, with no effect of tilth or simulated rainfall treatments (Figure 6). At a finer scale (> 0.25 mm), the change in WSA between planting and harvest was greatest where no simulated rainfall was applied at planting or emergence (Figure 6). The absolute change in WSA in both simulated rainfall treatments was small but it decreased from planting to harvest (-0.02) whereas the change over the same period was greater where no simulated rainfall was applied prior to emergence (-0.12). Between emergence and harvest, there was no effect of tilth or rainfall treatments on either fraction of WSA but there was a small overall decrease in WSA > 2 mm (-0.05) and > 0.25 mm (-0.07) (Figure 6).

Figure 6. Expt 2015-1: effect of tilth treatment on proportion of water stable aggregates by weight at planting, emergence and harvest. Coarse, ■; Fine ▨. Mean of three simulated rainfall treatments. Error bars based on 15 D.F.



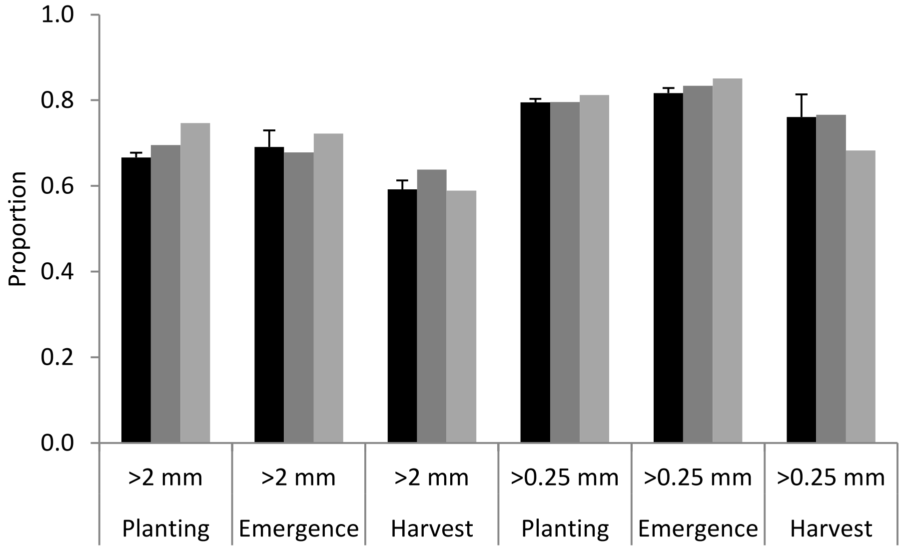
In Expt 2015-2, there was no significant effect of destoning depth on WSA (> 2 and > 0.25 mm) at planting, emergence or harvest (Figure 7). From planting and emergence to harvest, the overall trend was for WSA > 2 mm to remain constant but for WSA > 0.25 mm to decrease (Figure 7).

Figure 7. Expt 2015-2: effect of destoning depth on proportion of water stable aggregates by weight at planting, emergence and harvest. 25 cm, ■; 37 cm, ▨; 45 cm, □. Error bars based on 6 D.F.



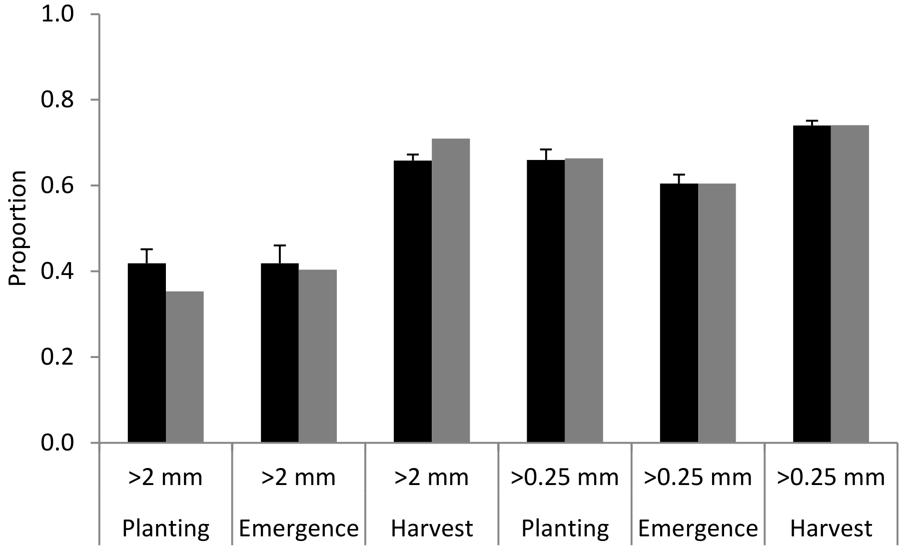
At planting in Expt 2015-3, shallow and commercial-depth destoning treatments had a smaller proportion of WSA > 2 mm than the Deep treatment but there was no effect of destoning depth on WSA > 0.25 mm at this time (Figure 8). At emergence and harvest, there was no effect of destoning depth on either fine or coarse WSA (Figure 8). The change in WSA > 2 mm between planting and harvest was greater for Deep than Shallow or Commercial destoning depths and the overall trend was for WSA to decrease (Figure 8). There was no effect of destoning depth on the change in WSA > 0.25 mm between planting and harvest. In the interval between emergence and harvest, WSA in both size fractions decreased by *c*. 0.094 but there was no effect of destoning depth.

Figure 8. Expt 2015-3: effect of destoning depth on proportion of water stable aggregates by weight at planting, emergence and harvest. 22 cm, ■; 27 cm, ■; 33 cm, ■. Error bars based on 6 D.F.



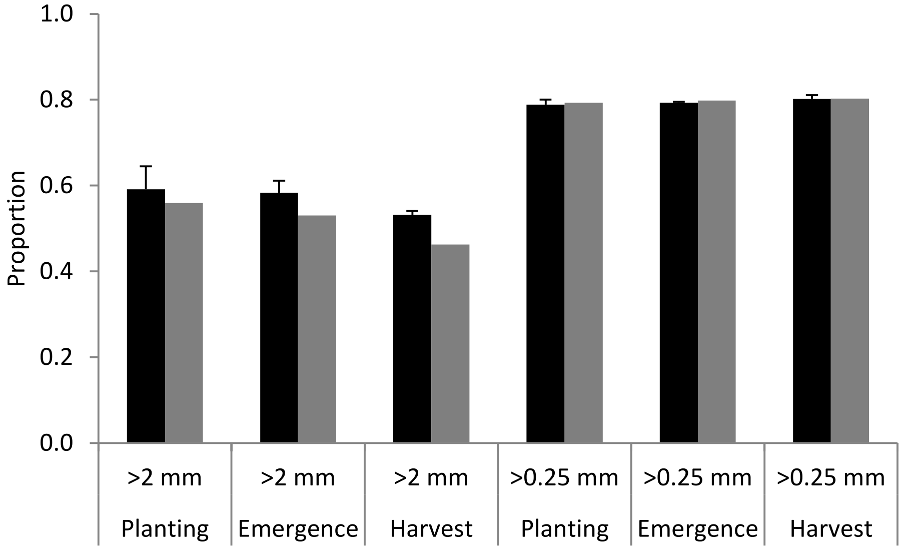
In Expt 2015-4, there was no effect of web pitch or destoner depth on the proportion of WSA in either size fraction at planting or emergence (Figure 9). At harvest, the 50 mm pitch treatment had more WSA > 2 mm than the 40 mm but there was no web-pitch effect with WSA > 0.25 mm (Figure 9). There was little change in the proportion of WSA between planting and emergence. The increase in WSA from emergence to harvest was large for WSA > 2 mm (0.27 ± 0.051) but smaller for WSA > 0.25 mm (0.07 ± 0.017).

Figure 9. Expt 2015-4: effect of destoner web pitch on proportion of water stable aggregates by weight at planting, emergence and harvest. 40 mm, ■; 50 mm, ■. Data are means of two destoning depths. Error bars based on 9 D.F.



In Expt 2015-5, there was no effect of cultivation depth or intensity on WSA > 2 and > 0.25 mm at planting or emergence (Figure 10). At harvest, the Coarse regime had more WSA > 2 mm than the Fine, but there was no effect of cultivation intensity on WSA > 0.25 mm (Figure 10). There was no change in either size of WSA between planting and emergence but the change from emergence to harvest was for WSA > 2 mm to decrease slightly (-0.06 ± 0.055) and for WSA > 0.25 mm to remain unchanged throughout the season.

Figure 10. Expt 2015-5: effect of seedbed tilth cultivation regime on proportion of water stable aggregates by weight at planting, emergence and harvest. Coarse, ■; Fine, ■. Error bars based on 6 D.F.



4.4. Yield

In Expt 2015-1, there were no effects of tilth or simulated rainfall post-planting on yields or number of tubers (Table 8). However, both tilth and the simulated rainfall treatments affected tuber [DM]. Coarse soil produced a higher [DM] than the Fine and simulated rainfall at planting produced a higher [DM] than no rainfall or an event at emergence (Table 8). It is difficult to explain these effects given there were no effects on yield.

Table 8. **Expt 2015-1: effect of tilth type and simulated rainfall events on yield (t/ha), number of tubers > 10 mm (000/ha) and tuber [DM] (%). S.E. based on 15 D.F.**

Tilth	Simulated rainfall event	Yield (t/ha)	40-90 mm yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
Coarse	None	64.9	62.8	477	24.2
	Planting	66.9	64.4	518	23.0
	Emergence	64.9	62.3	509	24.7
Fine	None	66.5	64.3	524	23.0
	Planting	70.8	68.4	431	22.6
	Emergence	67.1	64.3	539	23.5
S.E.		4.96	4.95	28.7	0.33

In Expt 2015-2, Shallow destoning produced a higher yield than the Commercial and Deep destoning depths (Table 9), but there was no effect on the number of tubers or [DM]. There was no effect of destoning depth on yield, number of tubers or [DM] in Expt 2015-3 (Table 9).

Table 9. **Expts 2015-2 and 2015-3: effect of destoning depth on yield (t/ha), number of tubers > 10 mm (000/ha) and tuber [DM] (%). S.E. based on 6 D.F.**

Expt	Destoner depth (cm)	Total yield (t/ha)	40-90 mm yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
2015-2	Shallow (25)	64.4	62.9	376	16.7
	Commercial (37)	58.1	56.9	402	17.1
	Deep (45)	57.2	55.1	427	16.3
	S.E.	2.03	2.08	31.9	0.31
2015-3	Shallow (22)	67.2	66.7	317	17.9
	Commercial (27)	68.6	67.2	341	17.6
	Deep (33)	64.0	63.4	297	17.8
	S.E.	1.90	1.71	9.0	0.22

In Expt 2015-4, there was no effect of destoning depth or web pitch on yield, number of tubers or [DM] (Table 10).

Table 10. **Expt 2015-4: effect of destoning depth on yield (t/ha), number of tubers > 10 mm (000/ha) and tuber [DM] (%). S.E. based on 9 D.F.**

Destoner depth (cm)	Rear web pitch (mm)	Yield (t/ha)	40-90 mm yield (t/ha)	Total no. of tubers (000/ha)	Tuber [DM] (%)
Shallow (28)	40	69.4	68.0	446	22.3
	50	70.7	68.9	457	22.4
Commerical (36)	40	69.8	67.8	507	21.7
	50	69.3	67.2	480	22.1
S.E.		2.72	2.56	20.9	0.62

In Expt 2015-5, there was no effect of tilth on yield, number of tubers, tuber [DM] or proportion of tubers > 90 mm long (Table 11).

Table 11. Expt 2015-5: effect of seedbed tilth cultivation regime on yield (t/ha), number of tubers > 10 mm (000/ha) and tuber [DM] (%). S.E. based on 5 D.F.

Seedbed tilth	Yield (t/ha)	40-90 mm yield (t/ha)	Total no. of tubers (000/ha)	Proportion of tubers >90 mm long (%)	Tuber [DM] (%)
Coarse	52.8	51.7	302	47	22.7
Fine	54.5	53.2	325	44	22.4
S.E.	1.28	1.22	10.3	2.5	0.24

4.5. Tuber quality

In Expt 2015-1, in the Coarse treatment there was no effect of simulated rainfall on the proportion of tubers that would be packable (tubers with < 5 % surface area with common scab) but simulated rainfall at emergence or no rainfall in the Fine treatment reduced the proportion of tubers being acceptable for packing from the point of view of common scab compared with simulated rainfall at planting (Table 12). There was the same interaction between seedbed tilth and simulated rainfall regime on scab severity as with the proportion of packable tubers so that simulated rainfall at planting reduced severity compared with no irrigation or irrigation at emergence (Table 12). The reasons for these apparent differences in scab are unclear but they were not associated with the simulated rainfall mimicking the effects of irrigation at tuber initiation since the latest simulated rainfall event was *c*. 13 days before initiation. There was no significant effect of any treatment on tuber greening (Table 12) and no cracking was observed.

Table 12. Expt 2015-1: effect of tilth type and simulated rainfall events on proportion of packable tubers (< 5 % surface area (SA) with scab) and severity (percentage SA infected) of common scab and incidence of tuber greening. S.E. based on 15 D.F.

Tilth	Simulated rainfall event	Proportion <5 % SA (%)	Proportion <5 % SA (ANG)†	Severity (% SA)	Greening incidence (%)
Coarse	None	88.5	70.5	3.62	6.5
	Planting	88.0	70.0	2.27	8.0
	Emergence	91.0	72.8	2.40	7.5
Fine	None	84.0	66.7	2.82	8.5
	Planting	92.0	74.0	1.79	7.5
	Emergence	81.5	64.9	4.28	9.0
S.E.		-	2.03	0.341	2.77

†Angular transformation of proportion of tubers with < 5 % SA with scab

In Expts 2015-2 and 2015-3, the incidence and severity of scab was very low and there were no effects of destoning depth on the proportion of packable tubers, scab severity or greening (Table 13). There was no cracking observed in either experiment.

Table 13. Expts 2015-2 and 2015-3: effect of destoning depth on proportion of packable tubers (< 5 % surface area (SA) with scab) and severity (percentage SA infected) of common scab and incidence of greening. S.E. based on 6 D.F.

Expt	Destoner depth (cm)	Proportion <5 % SA (%)	Proportion <5 % SA (ANG)†	Severity (% SA)	Greening incidence (%)
2015-2	Shallow (25)	96.9	80.0	1.12	1.7
	Commercial (37)	96.5	79.8	1.20	2.6
	Deep (45)	97.8	82.9	0.91	2.7
	S.E.	-	1.38	0.129	0.85
2015-3	Shallow (22)	100.0	90.0	0.50	3.0
	Commercial (27)	100.0	90.0	0.50	3.0
	Deep (33)	100.0	90.0	0.51	4.0
	S.E.	-	0.00	0.003	1.41

†Angular transformation of proportion of tubers with < 5 % SA with scab

In Expt 2015-4, there was no effect of destoning depth on scab, greening or cracking and, importantly, no effect of using a very coarse-pitch rear web on the destoner versus a more traditionally-sized web (Table 14).

Table 14. Expt 2015-4: effect of destoning depth and web pitch on proportion of packable tubers (< 5 % surface area (SA) with scab) and severity (percentage SA infected) of common scab and incidence of greening. S.E. based on 6 D.F.

Destoner depth (cm)	Web pitch (mm)	Proportion <5 % SA (%)	Proportion <5 % SA (ANG)†	Severity (% SA)	Greening incidence (%)
Shallow (28)	40	98.0	83.2	1.34	3.7
	50	97.2	81.6	1.39	4.5
Commercial (36)	40	96.8	80.8	1.40	3.3
	50	96.5	80.1	1.42	4.9
S.E.		-	2.09	0.416	0.56

†Angular transformation of proportion of tubers with < 5 % SA with scab

Experiment 2015-5 was a processing crop but the proportion of green, mis-shapen and cracked tubers was assessed. There was no effect of the Coarse or Fine treatment on greening (mean 7.4 ± 3.40 % incidence) and there were no cracked or mis-shapen tubers observed.

5. CONCLUSIONS

The overall trend of cultivation depth and intensity on the soil variables measured was that they had little overall effect on density and aggregate size distribution of soil within the ridge. Shallow, less intensive destoning (including widening the gaps in star separators or increasing the web pitch) often produces a visually cloddy surface to the bed prior to planting and this convinces growers that they may have a potential problem with respect to damage levels or clod at harvest. However, measurements showed that internally within the bed, the size distribution of aggregates was similar at harvest irrespective of cultivation intensity and the amount of diesel consumed during cultivation. Differences in aggregate size distribution are often created at planting by varying the intensity of rotary and destoning cultivation, but these largely disappeared by emergence and tuber initiation, the critical phase for having finer soil in the ridge to control common scab. This does not negate the fact that there are large differences between soil types and sites, but altering the operation of the cultivation tools at planting seems to be a relatively ineffective means of producing a ridge of the optimum range of aggregate size.

Soil density in the ridge generally increased during the season as a consequence of consolidation 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. The exception was Expt 2015-5, where ridge density decreased from planting to harvest.

The clay content of the soil was the over-riding factor in mean aggregate size and the proportion of aggregates > 6 mm, with higher clay content leading to larger aggregates. In both projects, soil OM was only loosely related to clay content, with high clay content soils generally having greater OM content than sandy soils, but there was a range of OM content in the soils tested owing to previous cropping and practice of manuring.

Analysis of the data collected both projects does not allow the optimal ped size distribution for seedbeds to be determined but the data indicate ridges should be composed of larger aggregates in sandy soils and of similar aggregate sizes to that achieved commercially on clay soils currently. There were very few examples of excessively cloddy seedbeds produced on heavy soils as most clod under such circumstances was removed to the furrow by destoners. There were examples of overly-fine seedbeds produced on sandy soils, largely as a consequence of low OM, excessively deep destoning and finer-pitch webs (often deemed a necessity on stony soils). Water stable aggregates tended to decrease between planting or emergence and harvest, but most of the changes were small (-0.02 to -0.07). In one experiment however, on soil composed of fine sand and silt, WSA increased significantly between planting and harvest. In line with effects on aggregate size distributions, cultivation machinery had surprisingly little effect on WSA.

Producing the optimum aggregate size distribution with existing equipment may prove difficult on certain soils and the main problem lies in not producing excessively-fine aggregates in the pursuit of breaking down larger clods. Destoning / declodding is largely carried out by machines that operate on two principles: traditional web-only based machinery and star machines. Web-only machines were developed in the 1970’s at the Scottish Institute for Agricultural Engineering to remove stones from ridges and reduce damage to tubers at harvest and are still the most effective design currently available to separate stones from soil, albeit with a slow rate of work. During the 1980’s, a pressure to work soils faster and under wetter conditions lead to development of star machines, which have a series of rollers with ‘star’ fingers at the front of the machine combined with web(s) at the rear to achieve the final separation of over-sized clods. Star machines are more suitable for breaking up clods than web machines, but there is a tendency for operators to close up the gaps between star rollers to avoid stones being pulled through into the seedbed but this leads to excessive grinding of soil at the front of the machine, particularly when a new set of stars is used.

The cultivation window in spring depends on the soil type and wetness. At least 20 cm of soil is required for a potato seedbed and on heavier soils, soil can be above the plastic limit for cultivation. During April, when most potatoes in the UK are planted, the weather can be extremely variable. Growers often experience the situation of soil being too wet at depth yet drying rapidly on the surface as the day warms up. Primary cultivations involving inversion of the soil often brings large clods of wet, unweathered soil onto the surface. This can dry hard within a few hours, resulting in slow rates of destoning or the implementation of bedtilling 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.

Tuber quality (common scab, cracking and greening) was largely unaffected by destoning depth, aggressiveness of destoning or type of destoning machine but it should be noted that all experiments involving packing varieties were grown with irrigation scheduled using the NIAB CUF irrigation model. Previous AHDB Projects (e.g. R448, Stalham *et al.* 2015) have shown the importance of irrigation management for controlling scab. These two soils projects have shown that, providing irrigation is available, soil structure is less important in controlling common scab than may be thought.

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 and few elements of risk. Destoning to produce beds 27-28 cm deep 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. There is also an opportunity to reduce the reliance on bedtilling to reduce clod size and improve work rates of destoners. Frequently, bedtillers are used to speed up work rates of declodding machinery but this project and work at AHDB SPot Farm 2015 has demonstrated that this shows negligible improvements in speed when soils are cultivated at their optimal depth. It is only when soils are cultivated deeply that bedtilling can significantly speed up declodding. It would be better to identify areas in fields likely to suffer from clod production at bedforming and bedtill only these areas and then only shallowly (15-20 cm rather than 25-35 cm). Most clods are located on the surface of bedformed beds and rotavating the entire bed wastes labour, energy and fuel and slows the entire planting operation. 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 20-40 % faster with shallower beforming and destoning and reducing the reliance on bedtilling could have a much larger effect on preventing yield loss than persisting with standard-depth destoning. Importantly, there would be no loss in tuber quality or damage and growers would have a significantly improved financial return on their crops.

6. REFERENCES

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