Report 2011-2012

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

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CONTENTS

1. SUMMARY 4

2. INTRODUCTION 6

3. MATERIALS AND METHODS 8

4. RESULTS 11

4.1. Soil water content, bulk density and penetration resistance 12
Ridge bulk density 13
4.2. Soil grading... 13
4.3. Yield and tuber quality 15
4.4. Soil mineral nitrogen 18
4.5. Total dry matter yield and N uptake 18
4.6. Commercial field survey 19

5. DISCUSSION 21

6. CONCLUSIONS...22

7. REFERENCES 23

8. ACKNOWLEDGEMENTS 23

1. SUMMARY

This project aimed to provide better quantitative relationships between the cultivatability, organic matter, depth of cultivation and wetness of soil and crop responses. Through avoiding damaging soils by untimely and excessive cultivation, growers will improve soil stability, improve cultivatability, reduce energy consumption, increase the efficiency of nitrogen and water use by the crop and minimise losses of nitrogen to the environment. This initial one-year project forms the basis for more extensive future work that complements other related Potato Council projects.

Four replicated experiments were conducted on a range of soils (loamy sand to clay loam), where cultivation treatments consisted of different destoning/declodding depths and production of coarse or fine clod structure within beds using variations in star spacing and rotation speed on Grimme destoners. In one experiment, three ridge profiles (rounded, trapezoidal and textured-surface) and two consolidations (loose and firm) were created using a commercial Grimme planter with ridging hood adaptions. In another experiment, plots were established with either 200 kg/ha nitrogen fertilizer or no nitrogen in combination with cultivation depth to quantify the effects on crop recovery of soil and fertilizer derived-nitrogen. The project also continued to develop the findings of Project R406 examining the effect of soil water content at cultivation and organic matter on soil bulk density in commercial fields.

The planting season was very dry in 2011 and all sites were easily cultivated, with deep destoning depths possible, even on fine clay loam soils. The actual depth achieved in shallow (20 cm) and normal (35 cm) depth destoning was similar across all experiments but there was more variation in the deepest depth achieved (47-54 cm), largely as a consequence of the depth of beds originally set up for the intended crop. Planting depth and interval from planting to emergence was similar for shallow, normal and deep destoning and shallow destoning did not lead to variable planting depth as is often reported when it is difficult to achieve adequate soil depth within beds. Bulk density and soil resistance after planting was greatly reduced between 25 and 50 cm following deep destoning compared with shallow. There was no evidence, contrary to what might be expected in normal seasons, that deeper cultivation resulted in more plastic shearing of soil at the destoner share-soil interface. There was no significant effect of destoning depth, aggressiveness of destoning and hood type or pressure on clod size distribution, number of tubers, tuber yield and quality (dry matter concentration, common scab or defects such as cracking or greening) in any of the four experiments. Destoning depth also had no significant effect on soil mineral nitrogen when measured at emergence or on nitrogen uptake.

There was a large range in soil water content both between and within commercial fields in 2011, including those with similar texture. The causes of these variations would be useful to understand, since it will clearly affect cultivatability. In all 13 commercial fields sampled, there was a significant positive linear correlation between the mean soil bulk density at 25-35 cm depth and the water content at cultivation but the magnitudes and relative changes in bulk density differed between fields. The overall mean and the variation in the slopes between fields fell between those measured in 2009 and 2010. However, combining the data from all 60 fields used in 2009-2011, there was a significant negative correlation between the slope of bulk density versus soil water content relationship and the average organic matter in each

field, showing that small increases in organic matter could result in significant improvements in cultivatability in coarse mineral soils.

The observations across all experiments in 2011 that seedbeds can be cultivated much shallower than the industry norm without detrimental effect on yield or quality is very useful information, as it allows potential savings in fuel, labour, contractor costs and equipment depreciation as well as faster work rate. An assessment of fuel consumption and rates of work showed that shallow compared with normal destoning depth could reduce the fuel consumption from £19.90 to £9.60/ha and improve spot rates of work from 4.0 to 6.8 ha/day. If generally suitable to adopt, the latter would increase the opportunity for many growers to cultivate soils within their windows of workability, particularly in wet seasons, since they often work machinery to capacity during the planting period.

2. INTRODUCTION

Potato Council-funded work in 2007-2010 (Project R406) showed that the relationships between soil bulk density, organic matter (OM) 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 OM 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 whilst above its plastic limit resulted in a consistent 7-17 % increase in bulk density and an increase in soil resistance (strength) compared with cultivating drier soil but yield losses were not related to the increases in bulk density or resistance. 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. Project R452 aims to provide better quantitative relationships between the cultivatability, OM, depth of cultivation and wetness of soil and crop yield and quality responses.

Earlier Potato Council-funded projects (e.g. R273 and R405) concentrated on understanding some of the factors that limit nitrogen (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 texture, OM and previous cropping history. Furthermore, total N uptake was often much more than would be expected from estimation of soil nitrogen supply (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 cultivation work was to measure soil mineral N and N uptake in crops grown in beds cultivated to contrasting depths. This initial one-year project was undertaken to form the basis for more extensive work in 2012-2014 that complements other related Potato Council projects.

As part of the project, an extension of the experimental programme established in Project R406 was continued on a more limited scale than in 2009 and 2010. Thirteen fields managed by Frontier Agriculture staff were identified in East Anglia prior to planting with soil types ranging from sandy loam to clay loam where cultivating too deeply at planting during March and April in most seasons could lead to soil compaction. The relationship between soil physical characteristics (bulk density, strength and ped size distribution) measured post-planting and soil water content, texture and organic matter was investigated and data collected added to the results produced in Project R406.

3. MATERIALS AND METHODS

In the main part of the project, there were four experiments conducted on external sites in Norfolk investigating the effect of destoner depth and sieving aggressiveness on soil parameters and crop yield and quality. The planting season was very dry and all sites were easily cultivated, with deep destoning depths possible. All experiments used a common make and model of destoner (Grimme Combistar CS150) as supplied by growers or Grimme UK Ltd (Expt 3). Soil was bedformed to sufficient depth to produce the grower's specifications for their standard depth of destoning (34-38 cm). The machines had 40 mm pitch rear webs except in Expt 4 where the web had a pitch of 28 mm. Drivers of machines were asked to destone a section of bed at their normal depth, forward speed, star spacing, shaft rotation and agitation/clod web settings and these were recorded. The forward speed was then adjusted to a set value and the depth and front star axle spacing altered to suit the treatment being applied. With the deep treatments, the destoner was allowed to penetrate as deep as the machine and bed height would allow. An attempt was made to produce fine and coarse seedbeds by closing star axle spacing to full over-lap or the axle spacing to the widest setting, respectively. Each plot comprised of two beds. Data were collected on the forward speed (all Expts) and fuel consumption and CO2 production (Expt 4 only) for each plot.

Experiment 1 was conducted on a sandy loam soil (70 % sand, 14 % silt and 16 % clay) with 1.4 % OM content at Hill Farm, South Pickenham farmed by Spearhead Marketing Ltd. The experiment was planted on 20 April 2011 using 45-55 mm Linton seed at a within-row spacing of 28 cm in 91 cm rows. It was a randomized block design with six replicates of factorial combinations of two destoning depths (Shallow; Deep) and two levels of N fertilizer (0; 200 kg N/ha) applied by the planter and incorporated into the bed in front of the opening shares. Plots were 20 m long and two beds (four rows) wide, with the harvest area being confined to the middle 5 m of each plot.

Experiment 2 was conducted on a clay loam soil (39 % sand, 42 % silt and 20 % clay) with 2.1 % OM content at Goulders, Felmingham farmed by LF Papworth Ltd. The experiment was planted on 26 April 2011 using 45-50 mm Pentland Dell seed at a within-row spacing of 31 cm in 91 cm rows. It was a randomized block design with four replicates of factorial combinations of three destoning depths (Shallow; Normal; Deep) and two degrees of aggressiveness of declodding (Coarse; Fine) created by altering the star spacing. Plots were 30 m long and four rows wide, with the harvest area being confined to the middle 5 m of each plot.

Experiment 3 was conducted on a clay loam soil (43 % sand, 37 % silt and 20 % clay) with 1.8 % OM content at Eversons, North Burlingham farmed by Greenseed International Ltd. The experiment was planted on 28 April 2011 using 35-45 mm Maris Piper seed at a within-row spacing of 20 cm in 91 cm rows. Treatments were all combinations of destoner depth (Shallow; Deep), planter hood type (Cage; Round; Trapezoidal) and planter hood pressure (Low; High). The different hood types were swapped on a Grimme GB215 planter. The experiment was a split-plot design with hood type as main-plots and destoner depth and hood pressure as sub-plots. There were three replicates and plots were 30 m long and four rows wide, with the harvest area being confined to the middle 5 m of each plot.

Experiment 4 was conducted on a loamy sand soil (82 % sand, 11 % silt and 6 % clay) with 1.7 % OM content at Gravel Pit, Hilborough farmed by Greenseed International Ltd. The experiment was planted on 14 July 2011 using 35-45 mm Maris Peer seed at a within-row spacing of 17 cm in 61 cm rows. It was a randomized block design with four replicates of factorial combinations of three destoning depths (Shallow; Normal; Deep) and two degrees of aggressiveness of declodding (Coarse; Fine) created by altering the star spacing. Plots were 30 m long and six rows wide, with the harvest area being confined to the middle 5 m of each plot.

In Expts 1 and 2, the soil water content was measured using a Delta-T Devices Theta Probe immediately prior to destoning bedformed soil. Measurements were taken in six replicate areas of the experiment by excavating a pit in the centre of the bed to 60 cm and measuring the water content on all four walls of the pit at 10 cm depth intervals.

Experiments 1 and 4 were irrigated according to a schedule provided by CUF, whilst Expts 2 and 3 were unirrigated. Plant emergence was recorded every 2-3 days in each plot by counting the number of plants emerged in the central harvest rows. A final harvest of 3 m from a single row was taken in August-October. 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 2-4, 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 were also assessed for type, incidence and severity of tuber cracking and growth defects at final harvest. In Expts 1 and 2, 50 tubers from each plot were hand-harvested and impacted on the stolon end with 0.5 J energy using a falling bolt (Stalham 2008). Following 24 h at 35 °C, tubers were peeled at the impact site and a count made of the number of peels taken to remove the bruise. In Expt 1, 50 tubers per plot were selected from the elevators of windrowed, machine-harvested tubers. Two weeks later, the tubers were peeled using an abrasive rumble peeler and the number of bruises per tuber counted.

The dry bulk density of the soil was measured at 20, 25, 30, 35, 40, 45 and 50 cm by inserting a stainless steel soil sampling ring (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 gently 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 knife 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.

Soil resistance readings were taken using an Eijkelkamp Penetrograph penetrometer (1 cm2 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.

Ridge bulk density and ped size distribution was measured by drying and grading a large-volume (4 l) soil sample taken at planting. After removing 2 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. This procedure was repeated on the adjacent ridge. 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 1, soil sample cores were taken on 24 May and 6 September using a 55 mm external 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 within 24 hours to NRM Ltd for analysis for soil mineral N (SMN).

In 13 commercial fields where the agronomy was managed by Frontier Agriculture, soil water content at 25 cm depth was measured using a Delta-T Devices Theta Probe ML2 and HH2 Moisture Meter at 12 locations on a 50 $\times$ 50 m grid pattern in one area of each field just prior to the primary cultivations at planting. These locations were accurately mapped so they could be returned to later in the season. Soil bulk density at 25-30 and 30-35 cm depth below the top of the ridge or bed was measured at each location in each field between June and August. Ped size distribution was measured using the same method as Expts 1-4 at three of the 12 locations.

4. RESULTS

The planting season was very dry in April and May 2011 and all sites were easily cultivated, with deep destoning depths possible, even on fine clay loam soils. The actual depth achieved in shallow (20 cm) and normal (35 cm) depth destoning was similar across all experiments but there was more variation in the deepest depth achieved, largely as a consequence of the depth of beds originally set up for the intended crop (Table 1). In Expts 1 and 2, the axle on the destoner graded the top of the destoned bed once depth exceeded c. 45 cm, so it was difficult to produce a deeper finished bed. The mean forward speed achieved in shallow treatments was 4.3 km/h, nearly three times as fast as for deep cultivation, with a 70 % faster rate than normal depths on sites where this comparison was possible (Table 1). Fuel consumption was recorded in Expt 4 and averaged 14 l/ha for shallow, 29 l/ha for normal and 47 l/ha for deep.

TABLE 1. SPEED AND ACHIEVED DEPTH OF DESTONING IN EXPTS 1-4. S.E. BASED ON 15 D.F. EXCEPT EXPT 3 (17)

	Forward speed (km/h)			Achieved depth (cm)			
Destoner depth	Shallow	Normal	Deep	Shallow	Normal	Deep	S.E.
Expt 1	4.4	-	1.4	20		47	1.1
Expt 2	4.4	2.5	1.4	19	33	48	1.0
Expt 3	4.8	-	1.6	21	-	54	1.5
Expt 4	3.7	2.2	1.5	19	37	51	1.2
Mean	4.3	2.4	1.5	20	35	50	-

Planting depth and interval from planting to emergence was similar for shallow, normal and deep destoning (Table 2) and the coefficient of variation for planting depth was the same for shallow, normal and deep destoning, indicating that shallow destoning did not lead to variable planting depth as is often reported when it is difficult to achieve adequate soil depth within beds.

TABLE 2. PLANTING DEPTH AND DAYS TO EMERGE IN EXPTS 1-4. S.E. BASED ON 15 D.F. EXCEPT EXPT 3 (17)

	Planting depth (cm)				Days to emerge			
Destoner depth	Shallow	Normal	Deep	S.E.	Shallow	Normal	Deep	S.E.
Expt 1	13.3	-	15.2	0.35	32	-	32	0.2
Expt 2	14.2	14.0	15.2	0.08	26	33	27	0.2
Expt 3	13.2	-	13.1	0.53	24	-	24	0.3
Expt 4	13.1	13.6	13.6	0.39	15	15	15	0.2
Mean	13.7	13.8	14.3	-	24	24	25	-

4.1. Soil water content, bulk density and penetration resistance

Where soil water content was measured throughout the profile immediately prior to destoning, the soil was drier between 25 and 50 cm than in previous seasons in the Frontier soil survey project. Figure 1 shows the soil water content throughout the profile in deep beds immediately prior to destoning Expt 1 and Expt 2. In both experiments, the soil was drier at 20 cm than deeper in the profile but the water content at 35 and 50 cm depths was similar and drier than the estimated plastic limit for a typical sandy loam (Expt 1) and clay loam (Expt 2).

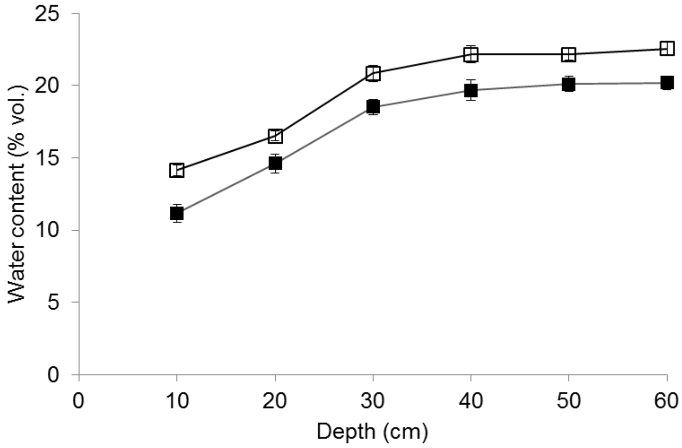

FIGURE 1. PROFILE OF SOIL WATER CONTENT IN DEEP BEDS IMMEDIATELY PRIOR TO DESTONING. ■, EXPT 1; □, EXPT 2.

Bulk density and soil resistance after planting was greatly reduced between 30 and 50 cm following Deep destoning compared with Shallow. There was no evidence, contrary to what might be expected in normal seasons, that deep cultivation caused a significant degree of compaction caused by plastic shearing of soil at the destoner share-soil interface. Figure 2 shows that bulk density and soil resistance measured at planting were closely correlated in Expts 1 and 2. The overall reduction in soil resistance between Shallow and Deep destoning at both sites would be expected to allow roots to reach 50 cm depth c. 7 days earlier in deep-destoned plots, thereby increasing the potential rooting depth by 15-20 cm which would be potentially most advantageous on the unirrigated site used for Expt 2.

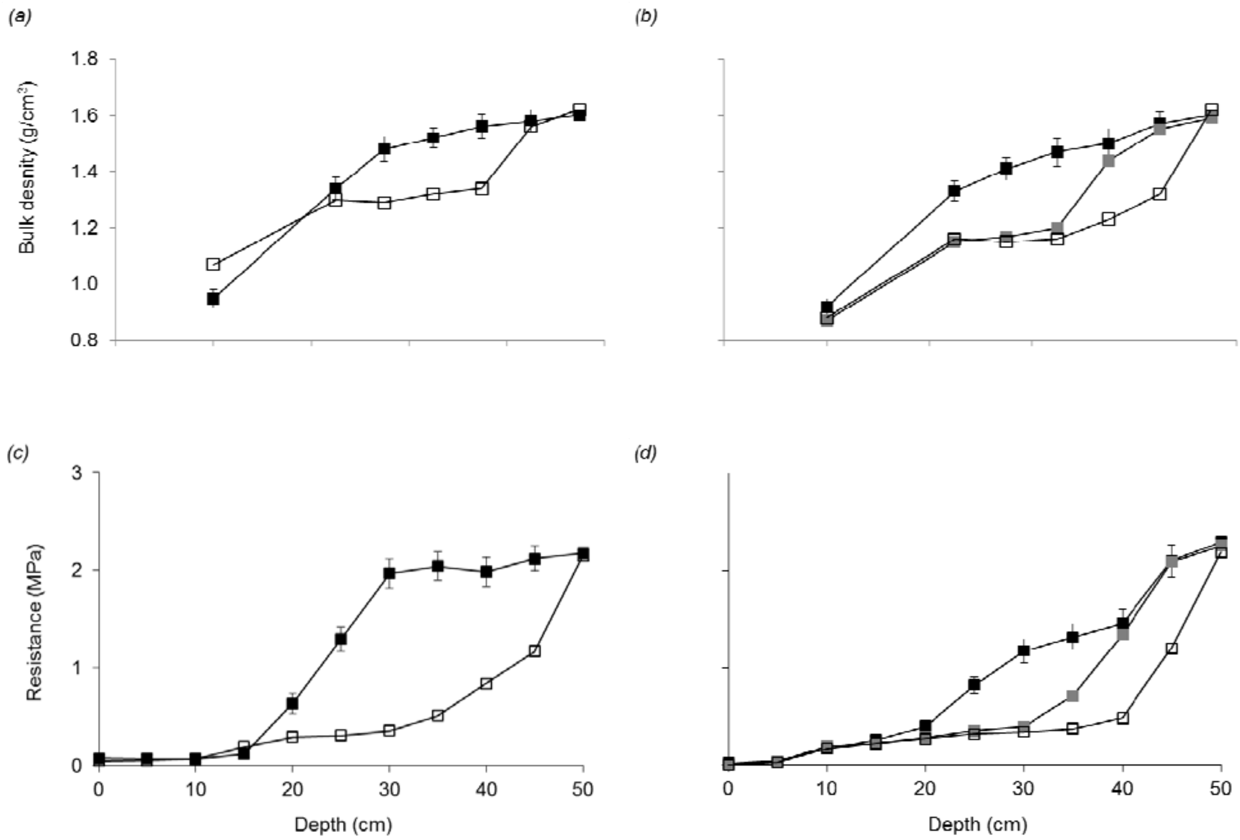

FIGURE 2. EFFECT OF DESTONING DEPTH ON SOIL BULK DENSITY AND PENETRATION RESISTANCE. BULK DENSITY: *(A)* EXPT 1; *(B)* EXPT 2. RESISTANCE: *(C)* EXPT 1; *(D)* EXPT 2. ■, SHALLOW; ■, NORMAL; □, DEEP. MEAN OF TWO N REGIMES IN EXPT 1 AND TWO AGGRESSIVENESS TREATMENTS IN EXPT 2.

Ridge bulk density

The measurement of bulk density using large (4 l) sampling volume reflects the packing density of soil in finished ridge and is likely to be affected by ped size distribution, the degree of consolidation created by the planter covering shares and any subsequent slumping of the ridge through erosion or soil particle movement in water percolating through the ridge.

In Expt 1, deep destoning increased ridge bulk density (1.07 ± 0.035 g/cm3) compared with shallow (0.95 g/cm3). In Expt 2, the packing density was low compared with the other sites examined and there was no effect of destoning depth or aggression on ridge bulk density (0.91 ± 0.022 g/cm3). Similarly, in Expt 3 there was no effect of destoning depth, hood type or pressure on ridge bulk density (1.08 ± 0.038 g/cm3), although there was some indication that the trapezoidal ridge hood produced less consolidation than cage or round covering hoods.

The ridge bulk density in commercial fields ranged from 0.98 to 1.31 g/cm3, and the mean density (1.12 ± 0.105 g/cm3) was similar to 2009 and 2010 results (1.10 ± 0.109) despite the very dry soils in 2011 (Table 11).

4.2. Soil grading

As previously mentioned, soils were dry when cultivating the experiments and the degree of aggressiveness of destoning had little visual effect on the surface of beds prior to planting. The heaviest soils were clay loam texture (Expts 3 and 4) but even these failed to produce significant clod content in beds, even in the absence of bed-tilling prior to destoning.

In Expt 1, there was no significant effect of destoning depth on ped size distribution (Figure 3) or mean ped size (8.3 ± 0.88 mm).

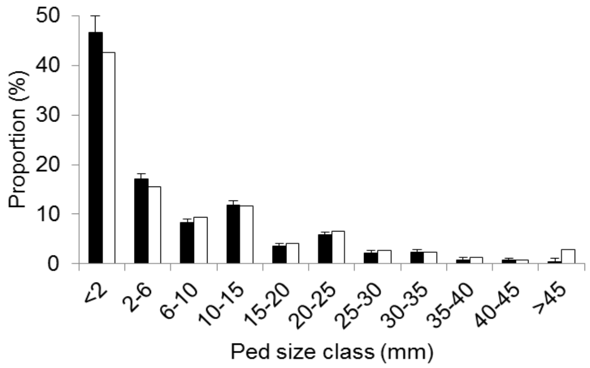

FIGURE 3. PED SIZE DISTRIBUTION IN EXPT 1. ■, SHALLOW DESTONING; □, DEEP DESTONING. DATA ARE MEANS OF TWO N LEVELS.

In Expt 2, mean ped size was decreased from 5.5 ± 0.19 mm to 4.8 mm by reducing star spacing and resulted in fewer clods in the 15-30 mm size grade (
Figure 4), but the effects were small and practically unimportant.

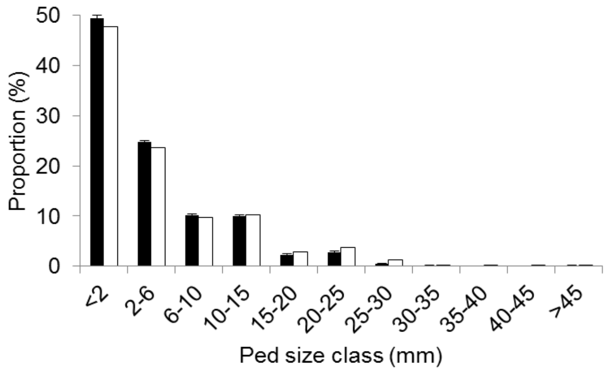

FIGURE 4. PED SIZE DISTRIBUTION IN EXPT 2. ■, NARROW STAR SPACING; □, WIDE STAR SPACING. DATA ARE MEANS OF TWO DESTONING DEPTHS.

In Expt 3, deep destoning reduced the mean ped size slightly to 6.0 ± 0.14 mm compared with shallow (6.5 mm), with more clods > 25 mm diameter with shallow destoning (Figure 5). The planter hood type and pressure had no effect on changing ped size distribution.

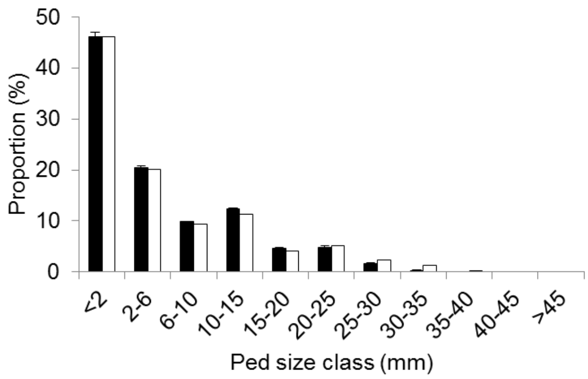

FIGURE 5. PED SIZE DISTRIBUTION IN EXPT 3. DATA ARE MEANS OF TWO HOOD PRESSURES AND THREE HOOD TYPES. ■, SHALLOW DESTONING; □, DEEP DESTONING.

Mean ped size in fields in the commercial survey range from 4.2 mm (sandy silt loam) to 10.2 mm (sandy loam). Mean ped size was smaller (6.3 ± 1.64 mm) in 2011 than in 2009-2010 (7.0 ± 2.53 mm), possibly as a consequence of the dry soils in 2011.

4.3. Yield and tuber quality

There was no significant effect of destoning depth, aggressiveness of destoning and hood type or pressure on yield, number of tubers or tuber [DM] in any of the four experiments (Table 3-6). In Expt 1, applying no N fertilizer reduced yield by an average of 12.7 ± 1.57 t/ha compared with 200 kg N/ha (Table 3).

TABLE 3. YIELD (T/HA), NUMBER OF TUBERS >10 MM (000/HA) AND TUBER [DM] (%) IN EXPT 1

Destoner depth	N applied (kg/ha)	Number of tubers	Yield	Tuber [DM]
Shallow	0	429	54.9	22.9
	200	413	68.2	22.6
Deep	0	417	53.2	23.7
	200	390	65.3	22.5
	S.E. (15 D.F.)	16.5	2.22	0.50

TABLE 4. YIELD (T/HA), NUMBER OF TUBERS > 10 MM (000/HA) AND TUBER [DM] (%) IN EXPT 2

Destoner depth	Cloddiness	Number of tubers	Yield	Tuber [DM]
Shallow	Cloddy	391	57.7	24.2
	Fine	362	57.4	24.3
Normal	Cloddy	372	56.0	24.5
	Fine	382	57.0	24.5
Deep	Cloddy	381	55.4	24.0
	Fine	395	56.5	24.9
	S.E. (15 D.F.)	15.1	2.26	0.47

TABLE 5. YIELD (T/HA), NUMBER OF TUBERS > 10 MM (000/HA) AND TUBER [DM] (%) IN EXPT 3

Destoner depth	Hood type	Number of tubers	Yield	Tuber [DM]
Shallow	Cage	373	26.1	16.5
	Round	411	27.6	16.8
	Trapezoidal	418	29.3	17.0
Deep	Cage	363	27.7	16.8
	Round	412	29.6	16.4
	Trapezoidal	417	28.8	17.0
	S.E. (17 D.F.)	22.9	1.80	0.27
	S.E. (same hood type)	24.7	1.70	0.30

TABLE 6. YIELD (T/HA), NUMBER OF TUBERS > 10 MM (000/HA) AN TUBER [DM] (%) IN EXPT 4

Destoner depth	Cloddiness	Number of tubers	Yield	Tuber [DM]
Shallow	Cloddy	725	26.1	17.2
	Fine	700	27.6	17.6
Normal	Cloddy	746	29.3	17.3
	Fine	726	27.7	17.1
Deep	Cloddy	739	29.6	17.6
	Fine	744	28.8	17.3
	S.E. (15 D.F.)	29.2	1.70	0.17

There was no effect of destoning depth, aggressiveness of destoning, hood shape or hood pressure on tuber quality (common scab or defects such as cracking) at the two sites where packing or seed crops were grown (Expts 3 and 4). In Expt 3, no irrigation was applied to this site and common scab severity was greater than would be expected from this soil type using well-scheduled irrigation. The similar values of common scab observed between treatments in Expts 3 and 4 are shown in Table 7 and Table 8.

TABLE 7. INCIDENCE AND SEVERITY OF COMMON SCAB IN EXPT 3

Destoner depth	Hood type	Hood pressure	Incidence < 5 % SA	Ang, incidence < 5 % SA	Severity (% SA)
Shallow	Cage	Low	90.9	72.4	5.23
		High	91.2	72.7	4.98
	Round	Low	89.7	71.3	6.02
		High	92.0	73.6	5.46
	Trapezoidal	Low	90.2	71.8	6.00
		High	90.8	72.3	5.55
Deep	Cage	Low	92.3	73.9	4.77
		High	91.5	73.0	4.89
	Round	Low	90.4	72.0	5.62
		High	88.8	70.4	6.24
	Trapezoidal	Low	90.6	72.1	5.02
		High	92.3	73.9	4.66
	S.E. (17 D.F.)		-	2.33	0.890
	S.E. (same hood type)		-	2.36	0.856

TABLE 8. INCIDENCE AND SEVERITY OF COMMON SCAB IN EXPT 4

Destoner depth	Cloddiness	Incidence < 5 % SA	Ang, incidence < 5 % SA	Severity (% SA)
Shallow	Cloddy	98.9	84.0	1.78
	Fine	97.8	81.5	1.62
Normal	Cloddy	97.2	80.4	1.56
	Fine	96.8	79.7	1.46
Deep	Cloddy	98.0	81.9	1.62
	Fine	97.4	80.7	1.56
	S.E. (15 D.F.)	-	2.02	0.126

The incidence of bruising and number of bruises in commercially-harvested tubers in Expt 1 was significantly greater in deep-destoned plots (60 ± 2.6 % incidence and 1.0 ±0.05 bruises per tuber) than in shallow-destoned (43 % and 0.6, respectively) despite fewer (large) stones in the ridges in Deep destoned plots. Bruising incidence in tubers harvested and impacted in a laboratory with controlled energy showed no difference between destoning treatments (data not shown).

4.4. Soil mineral nitrogen

In Expt 1, Destoning depth had no significant effect on SMN when measured on 24 May, at any position across the bed (Table 9) and the overall mean SMN (0-90 cm) was 134 kg N/ha. At final harvest in September, the average SMN to 90 cm depth was 37 kg N/ha and, again, destoning depth had no significant effect on the amount of N at any position across the bed profile.

TABLE 9. EFFECT OF DESTONER DEPTH AND SAMPLING POSITION ON SOIL MINERAL N (KG N/HA, 0-90 CM) ON TWO OCCASIONS IN EXPT 1†

Date of sampling	24 May		6 September	
Destoner depth	Shallow	Deep	Shallow	Deep
In centre of bed ('A')	141	132	31	40
Between adjacent plants ('B')	166	138	38	34
In wheeling ('C')	125	102	44	37
Mean of Destoner depth	144	124	38	37
Grand mean	134		37	
S.E. (10 D.F.; Destoner depth)	11.6		2.5	
S.E. (10 D.F.; Destoner depth × position)	20.0		3.6	

†Data are means of 0 N treatment only

4.5. Total dry matter yield and N uptake

The crop in Expt 1 was sampled on 6 September when the canopy was senescing. Destoning depth had no effect on tuber or total DM yields but increasing the N application rate from 0 to 200 kg N/ha increased tuber DM yields by c. 2.5 t/ha and total DM yield by c. 4 t/ha (Table 10). Depth of destoning had no effect on either tuber or total N uptake. When averaged over the two destoning depths, tuber N uptake was increased from 103 to 247 kg N/ha when the N application rate was increased from 0 to 200 kg/ha. Similarly, the main effect of applying N fertilizer was to increase total (haulm and tuber) N uptake from 118 to 273 kg N/ha. The lack of effect of destoning depth on N uptake is consistent with the cultivations having little effect on the amount of SMN measured in the soil in May and there probably being little advantage from a potential increase in rooting density in deep-destoned plots. The soil in Expt 1 was a sandy loam with 1.4 % soil organic matter. There was no recent history of organic manure usage and the previous crop was a cereal, so for the purposes of N recommendations, this field would be placed in Soil Supply Index 0 or 1 and would be expected to supply < 80 kg N/ha to the potato crop. However, measurements of SMN and total N uptake by the crop showed that soil N supply from this soil was larger than expected. The amount of SMN found in the soil in the spring and the total N uptake of the unfertilized crop was equivalent with a Soil Supply Index of 3 for this field. Unexpectedly large total N uptakes have been found in many unfertilized crops and may, in part, be due to the intensive cultivations used to create potato seedbeds.

TABLE 10. EFFECT OF DESTONER DEPTH AND N APPLICATION RATE ON TUBER AND TOTAL DM YIELD AND N UPTAKE IN EXPT 1

Destoner depth	Shallow		Deep		S.E.
N applied (kg/ha)	0	200	0	200	(15 D.F.)
Tuber DM yield (t/ha)	12.6	15.4	12.6	14.7	0.64
Total DM yield (t/ha)	13.9	17.7	14.0	16.4	0.77
Tuber N uptake (kg N/ha)	98	247	108	248	8.3
Total N uptake (kg N/ha)	112	275	125	271	9.0

4.6. Commercial field survey

There was a large range in soil water content both between and within fields in 2011, including those with similar texture. The minimum range of soil water content within fields was 4.8 %, maximum 10.3 % and mean 6.8 % and therefore similar to 2010 but less variable than 2009. The causes of these variations would be useful to understand, since it clearly will affect cultivatability. In all 13 fields sampled, there was a significant positive linear correlation between the mean soil bulk density at 25-35 cm depth and the water content at cultivation but the magnitudes and relative changes in bulk density differed between fields (Table 11). On average, only 52 % of the variation in soil bulk density was explained by differences in the water content at cultivation, indicating other factors play an important role in bulk density. However, the overall mean and the variation in the slopes between fields of the relationships between bulk density at cultivation depth and soil water content at cultivation were intermediate between values obtained in 2010 (0.0214 ± 0.00565 g/cm^3/%) and 2009 (0.0261 ± 0.0 g/cm^3/%). There was, as in 2009-2010, no overall relationship between bulk density at cultivation depth and soil water content at cultivation when examining the entire data set. The soil textures had a narrower range than in 2009 and 2010 and ranged from sandy loam (13 % clay) to clay loam (23 % clay), with a mean clay content of 17 ± 3.2 %. The range in organic matter (1.6-2.8 %) was also narrower than in previous seasons (0.9-3.5 %). However, combining the data from all 60 fields used in 2009-2011, there was a significant negative correlation between the slope of bulk density vs soil water content relationship and the average organic matter in each field, showing that small increases in organic matter could result in significant improvements in cultivatability in coarse mineral soils (Figure 6).

TABLE 11. SUMMARY OF 13 FIELDS SURVEYED IN 2011: TEXTURE, ORGANIC MATTER (OM, %), BULK DENSITY AT CULTIVATION DEPTH (G/CM^3), SLOPE OF BULK DENSITY VS SOIL WATER CONTENT RELATIONSHIP (G/CM^3/%), SIGNIFICANCE OF RELATIONSHIP (FPROB), PERCENTAGE VARIANCE ACCOUNTED FOR (VAR) AND RIDGE DENSITY (G/CM^3)

Field	Texture †	OM	Bulk density	Slope	S.E.	Fprob	VAR	Ridge density
Papworth 77	CL/SZL	2.0	1.43	0.0194	0.00425	0.001	64.3	0.95
AW Lamb 28	SZL	2.6	1.28	0.0252	0.00937	0.023	36.1	0.98
Lamb Weston G4	SL	2.2	1.33	0.0268	0.00870	0.012	43.5	0.98
Lamb Weston L02	SL	2.1	1.40	0.0223	0.00622	0.005	51.9	1.16
Wroxham Home 19	SL	2.3	1.27	0.0215	0.00627	0.007	49.3	1.11
HB Sands B3	CL	2.0	1.44	0.0196	0.00379	<0.001	70.1	1.16
Billockby Farms 2/3	SL	2.1	1.45	0.0290	0.00706	0.002	59.2	1.31
Billockby Farms 16	CL	2.7	1.43	0.0274	0.00918	0.014	41.9	1.20
Claydon A	SZL	2.1	1.35	0.0287	0.00803	0.005	51.7	1.14
HA Overton C14	CL/SZL	2.4	1.43	0.0204	0.00580	0.006	50.7	1.12
Harrison Chapmans	SL/SZL	2.8	1.34	0.0150	0.00420	0.005	51.7	1.12
Grove Farm 24	SCL	2.3	1.31	0.0182	0.00677	0.025	38.2	1.12
Joice Laddies Hole	SL	1.6	1.39	0.0252	0.00527	<0.001	66.5	1.25
Mean		2.2	1.34	0.0230	0.00653	-	51.9	1.12
S.E.		0.32	0.099	0.0044	0.00189	-	10.7	0.105

†SL = sandy loam, SZL = sandy silt loam, SCL = sandy clay loam, CL = clay loam

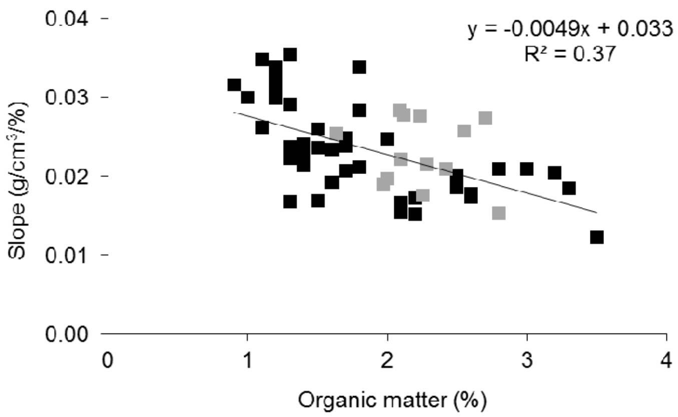

FIGURE 6. RELATIONSHIP BETWEEN THE SLOPE OF BULK DENSITY VS SOIL WATER CONTENT RELATIONSHIP AND THE MEAN ORGANIC MATTER PERCENTAGE IN EACH FIELD, 2009-2011. ■ 2011 DATA. SLOPE OF THE RELATIONSHIP: Y = -0.0049X + 0.033, PERCENTAGE VARIANCE ACCOUNTED FOR = 37 %.

5. Discussion

Soils in 2011 were very dry to considerable depth and many potential sites had been planted before the project commenced. Very large differences in the depth of seedbed with low strength and density soil were created by destoning between 20 and 50 cm depth which would be expected to appreciably improve rooting depth owing to faster root elongation between 20 and 50 cm. In Expts 1 and 2, the axle on the destoner tended to drag the top of the destoned bed once depth exceeded *c*. 45 cm, so it was difficult to produce a deeper finished bed. Where deeper beds were produced for destoning, depths > 50 cm were possible, *c*. 20 cm deeper than the industry norm. Some of the differences in seedbed resistance created by increasing destoner depth created might be expected to result in 20-25 cm deeper rooting (Stalham *et al*. 2007) which has the potential to considerably increase the quantity of water available to plants, thereby reducing the irrigation requirement. There was no indication that plastic deformation occurred at the deepest cultivation depths used in any experiment in 2011, which is rarely the case for April plantings in the UK (Stalham & Allison 2011) and experimental work in 2012-2014 aims to include sites where this does occur. The survey of commercial fields showed that small increases in organic matter could result in significant improvements in cultivatability in coarse mineral soils and this require further investigation.

Intended planting depth was slightly shallower than intended in shallow-destoned plots but the difference was < 2 cm and had no effect on the time taken for plants to emerge. 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. Aggressiveness of destoning did not affect any measured soil or plant growth factor significantly. Destoning depth did not affect tuber yield, quality or bruising but similar experiments will be repeated in 2012-2014 to test whether the results produced in a very dry planting season with good soil conditions at planting were atypical. However, shallower destoning clearly has the potential to reduce diesel consumption and improve work rates. In Expt 4, an assessment of fuel consumption and rates of work showed that shallow compared with normal destoning depth could reduce the fuel consumption from £19.90 to £9.60/ha and improve spot rates of work from 4.0 to 6.8 ha/day.

This study also confirmed earlier work that has shown that soils sometimes supply more N to the potato crop than anticipated using the SNS system (DEFRA 2010). It is likely that the generally good planting conditions found in 2011 were associated with the lack of effect of destoning depth on N uptake and crop growth. Similar work will be done in 2012-2014 to better understand the effects of cultivation on soil nitrogen supply and how soil conditions affect the efficiency with which the potato crop uses SMN.

6. CONCLUSIONS

The observations across all experiments that seedbeds can be cultivated much shallower than the industry norm without detrimental effect on yield or quality is very useful information, as it allows potential savings in fuel, labour, contractor costs and equipment depreciation as well as faster work rate. The latter will increase the opportunity for many growers to cultivate soils within their windows of workability, since they often work machinery to capacity during the planting season. It also showed that in seasons where soil is dry at depth, cultivation can be deeper than normal without damaging soil, but this does not benefit productivity or profitability. It highlights that if areas of fields could be identified where the risk of cultivation causing damage is high, then shallower than normal destoning in these areas would not be detrimental to tuber yield and quality as there would still be adequate depth of soil in the ridge or bed. Reported ease of harvesting and tuber damage levels were unaffected by seedbed depth, which should give growers the confidence to experiment more with depth.

Further analysis is needed to understand the causes of variation in soil water content both between and within fields with the same textural class, including the variation in organic matter contents in the different locations sampled in the field and the effect of cultivating these different areas at different depths. Once combined with new data, it is hoped the information from the survey data collected in 2009-2011 can help provide a useful set of recommendations for growers when cultivating different fields. A significant programme of work is planned for 2012-2014 which will utilize the data from this interim project. The new project will concentrate more on the effect of different cultivation treatments within each field rather than a standard cultivation programme.

7. REFERENCES

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