Paper 2

MECHANISATION IN POTATO PRODUCTION

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INTRODUCTION

The potato — a very popular and nutritious food, the basis of many tasty dishes and snack foods, and the raw material for the manufacture of products such as starch and alcoholic liquor. A pity, therefore, that its production, preparation and presentation to the purchaser can be fraught with so many perplexing problems — especially, though not exclusively, in the harvesting and post-harvest handling phases. In the solution of such problems machinery can play a very vital part. But the operation and management of that machinery will inevitably be accompanied by further problems.

This paper seeks to review something like a century's development and achievement in machinery for the potato crop and, by describing some recent developments and research, to suggest the type of mechanical assistance which may be available to potato growers of the future.

MECHANISATION — WHAT ARE THE PROBLEMS?

Of the problems associated with potato production, there are seven which have particular significance in the context of mechanisation.

- The tubers are very susceptible to damage, the nature and extent of which may be difficult to assess until several days after it has been inflicted.
- The usable part of the crop develops entirely below ground level, making it more difficult to recover than, for example, wheat.
- In both type and condition, soils within which the tubers develop are likely to be very variable from one district to another. These variations will often have a marked effect on machine performance and on wear rates of machine components.
- Planting the crop calls for the use of about 2.5 t/ha of seed, a far greater quantity of propagating material than is required for any other temperate zone crop.
- While the yield of a good crop (at about 40 t/ha) is far less than the 100 t/ha which might be expected from fodder beet, the total quantity of crop and "rubbish" which must be taken into the machine is surely the highest of any crop worldwide, at up to about 1000 t/ha. The nature and condition of the rubbish (haulm, weeds, soil, clods, stones) is also likely to be extremely variable.
- Much of the crop requires harvesting at a time of year when ground conditions are likely to be difficult (and sometimes impossible!) for the movement of heavy equipment, and weather conditions are often uncomfortable for outdoor work.
- The crop is subject to attack by a range of insects and diseases (and to competition from various weeds), against which protection must be provided. The most convenient way of giving this protection is often based on a tractor being driven through the growing crop — with possible detrimental effects on crop and soil.

FUNDAMENTALS OF SUCCESSFUL MECHANISATION

There are certain basic machinery management recommendations which apply equally to all types of machinery for all sorts of crops (selection of a quality machine for reliability and durability, availability of spare parts and skilled service, operator skill, routine preventive maintenance, reducing overhead costs through maximum utilization). Then there are some important guidelines, such as the three set out below, which have specific relevance to the potato crop.

- Tuber quality at the point of final use must be the paramount concern of everyone associated with handling at every stage. It is clear that, on some occasions, a compromise will have to be reached between minimum tuber damage and minimum time for completion of a certain operation. Also, much of the possibly careless handling, which may result in serious damage, takes place "beyond the farm gate".
- The care and skill devoted to each earlier operation (from seedbed preparation onwards) may strongly affect the ease and efficiency with which harvest may be completed.
- Careful planning should be undertaken for efficient "materials handling". Attention to detail in getting large weights of tubers per hectare into the planter

and away from the harvester may well be repaid through significant savings of time and money.

In giving detailed consideration to the problems and possibilities of mechanisation in potato production, it is convenient to concentrate on each of three phases in turn:

1. Establishing the crop and attending to its needs as it develops towards maturity.
2. Harvesting the crop, including transport to the grower's or purchaser's store.
3. Storing and handling the crop, and preparing it for sale.

This paper seeks to review only the first two of these phases.

ESTABLISHING AND TENDING THE CROP

Preparing the ground for planting

Basically, a fairly deep tilth is required, from which ridges of adequate size can be built to contain the expected crop at maturity. In the case of heavier soils — and particularly those with a tendency to form clods which become hard when dry — every effort must be made to minimise clod formation. This is important in helping to reduce clod-separation problems at harvest time, and calls for careful attention to one or more of the following:

- Avoiding excessive soil compaction during the production, harvesting and transport of the crop immediately preceding the potato crop.
- Minimizing the use of heavy tractors (or other heavy equipment), particularly when the soil is at a "sensitive" moisture content.
- Considering the use of rotary cultivators or power harrows driven from the tractor power take-off. Compared with "traditional" implements, like cultivators and disc harrows, this will call for far less pull from the tractor, and consequently less wheelslip, smearing and clod formation. But care must be taken to avoid making the tilth too fine!
- If ridging is required before planting it is as well to remember that "traditional" ridging mouldboards, used when the soil is moist, may have a tendency to smear the sides of ridges with resultant increased risk of clod formation. To combat this tendency, the Scottish Institute of Agricultural Engineering (SIAE) developed a power-driven rotary ridger (Anon., 1977). Several manufacturers produce machines which resemble rotary cultivators, with ridge-forming guides at the rear.

Parallel with the problem of clod separation at harvest, is that of stone separation and, over the years, a great deal of time and money has been spent on attempts to develop automatic means for achieving such separations in (or after) the harvester. However, if stones can be removed from the field before planting, problems at harvesting will be lessened and stone damage to tubers reduced.

Many companies have developed and marketed "stone pickers" aimed at taking stones right off the fields, including attachments to elevator-type potato diggers which can be used for lifting the "stone crop" and loading it into vehicles before the potato crop is planted. Further problems are likely to arise, however, particularly in regard to disposal of the unwanted stones. There have been proposals to separate stones, crush them and return them to the soil! Quite apart from the large amount of energy which the crusher would consume, many of the resultant stone fragments would probably have jagged edges which could cause more serious damage to potatoes during harvest than might the original uncrushed stones.

Originating from experiments carried out by some Scottish farmers in the early 1960's, the technique of "stone windrowing" seems to be achieving a fair measure of acceptance in Britain, Sweden, Germany and some other European countries (Witney, 1981, 1982). There are several variations on the stone windrowing theme, but they are all based on four stages.

1. Forming the field surface into a series of parallel "beds", each usually about twice as wide as the row spacing at which the crop is to be planted.
2. Digging the beds and separating stones, together with such large and hard clods as may be present.
3. Placing the stones in positions where they will not interfere with inter-row operations or harvesting. This usually involves either:
   - placement in fairly deep "grooves", formed by heavy-duty ridgers in between successive beds, and pressed down by tractor and machine wheels on later passes, or
   - surface placement in alternate "valleys" between ridges after the potatoes have been planted.

   (Where some quite large stones, say over about 150 mm nominal diameter, are likely to be encountered in a field, provision can be made on some machines for retaining them in a bin on the machine for removal to the headland).
4. Planting tubers in ridges formed from "stone-freed" soil.

The successful application of these techniques calls for very careful correlation between the stone windrowing, planting and harvesting phases. In some commercial examples, harvesters have been modified for stone windrowing, and planters have been built on to stone windrowers.

Mechanical planting

There has been a fairly long history of attempts to plant potatoes mechanically, and a patent was granted in Britain in 1857 for a planter with "... a rotary feeding device delivering to a rotary distributor" (Fussell, 1952). But for a long time, many of the mechanical planters depended on one riding operator for each row, who placed a tuber in each "compartment" of some form of spacing mechanism which was adjustably driven from a landwheel.

Several different mechanisms have been tried for picking up tubers from hoppers in fully automatic planters (cups on chains, spring-loaded fingers on rotating discs, sharp spikes on arms radiating from a rotating shaft). An operator is sometimes carried on such machines to detect (and, where possible, correct) mistakes made by the pick-up mechanism. As early as 1948, an official test was carried out in England of a French machine on which the "misses" arising in the operation of the pick-up mechanism were atomatically sensed and corrected by a special conveyor (NIAE, 1948).

The working of planter pick-up mechanisms can be rendered very erratic by the presence of excessive sprout growth. In some countries, seed potatoes are intentionally sprouted ("chitted") before planting. In such situations, it is important that the sprouts are not damaged by the planter mechanism: several machines have been designed specially with this in view.

One of the latest developments is the Smallford Setronic, first described in detail early in 1983 (Anon., 1983). This fully-automatic, two-row machine was designed by the SIAE and, thanks to a microprocessor-controlled system designed by the National Engineering Laboratory, Glasgow, it is able to travel at 9 km/h when planting at 300 mm spacing.

Tending the growing crop

In the earliest stages, this tending consists of inter-row grubbing with groups of tines followed by ridge re-shaping with ridging bodies. But often of greater importance is the protection of the crop (particularly through the application of chemicals) from the depredations of insects and diseases.

In tending the crop it is important not to create conditions that will cause problems at harvest time. Specifically, the separation of clods will be made more difficult as a result of wheelmarks between potato rows (particularly where the wheels are wide enough to compress the ridge edges). Clod-formation resulting from inter-row traffic will be accentuated by one or more of:

- greater clay content in the soil;
- greater moisture content in the soil;
- greater weight on the wheels;
- slippage of the driving wheels.

Where unfavourable combinations of these circumstances are likely, aerial spraying should be considered to keep wheeled traffic out of the crop.

HARVESTING THE CROP

One of the simplest mechanical aids to potato harvesting is the potato plough — resembling a ridging body with its mouldboards replaced by rods or slats. While it is certainly very gentle in its treatment of the potatoes, the plough does not expose the tubers efficiently for convenient picking up.

As long ago as the 1850's, diggers with moving parts were available, in both "spinner" form and "apron" (or elevator) form. The tubers commonly sustained quite serious damage from these machines (particularly from the spinner type). In the report on trials of several machines, held near Aberdeen in 1877, it was stated "... all the machines removed the potatoes from the soil too rapidly, and this injured the skins so that they could not be advantageously stored in pits" (Fussell, 1952). The early "complete harvesters" were often adaptations of apron diggers, making it possible for several "pickers" to ride on the machine and for the potatoes to be bagged (sometimes preceded by weighing) before being put down on the ground.

With increasing production of potatoes and diminishing supplies of suitable labour, the numbers of harvester types grew — as did their complexity, range of capabilities, rate of working and (unfortunately!) their weight and their price. In discussing the various features which may be combined within a single machine, it is convenient to consider separately each of the treatments which may be applied to a "harvest-ready" crop before it can be regarded as being ready for sale:

1. Removing the tops.
2. Digging the ridge.
3. Removing the soil.
4. Separating stones and clods (and some other "rubbish" such as damaged, diseased or undersized tubers).
5. Delivering to transport.
6. Transport from field to store.

Often the first five of these treatments are applied within a single machine, but local circumstances sometimes make separation into two or more phases desirable. For example:

- The tops may be removed several days before the ridge is dug.
- A one or two-row apron digger may be used for digging the ridge and removing the soil in such a way that potatoes (often accompanied by some "rubbish") from as many as four rows are laid in a single windrow. A few hours' exposure to the air will often encourage the skins to harden, with consequential reduction in the risk of tubers suffering from "skin scuffing" during subsequent handling. A harvester will then be used to pick up the windrows, separate stones and clods and deliver the tubers to the transport.
- Where the occurrence of stones and clods is not unduly high, all other operations can be carried out by one machine and stones and clods removed in the packing shed.

Removing the tops (and possibly weeds)

In the past, tops have often been removed before digging, either by burning with chemical sprays or by shredding with rotating knives or beaters. On the other hand, tops are sometimes taken into the harvesters, and are separated from the potatoes with a wide-pitch rod-link conveyor or other mechanical device. In either case, the presence of the tops (or the residue after attempts at burning or shredding) can contribute towards blockage problems in the vicinity of the lifting share.

Investigations are proceeding into the possibility of mechanically pulling the tops before the ridge is dug (Anon., 1982). Particularly in the case of "early" crops, it is necessary to ensure that tubers are separated from the stolons as the tops are pulled.

Digging the ridge

Many harvesters now use a divided "scoop-type" share, rather than the almost-flat blade share (which is still used on apron diggers). It has been shown that the profile cut by the scoop share corresponds very closely with the region within the ridge where potatoes tend to be concentrated, thus reducing the amount of soil (needlessly) dug at the edges of the ridge (just where cloddiness might have been aggravated by tractor wheelmarks during spraying). Both types of share sometimes become blocked with accumulations of roots or of top remnants or, under some conditions of soil type and moisture content, with soil which will not slide over the share surface.

In the late 1970's, the SIAE developed a 2-row share assembly consisting of two pairs of power-driven saucer-shaped discs (McRae, 1983). The larger disc in each pair is the digging disc, 900 mm in diameter with its concave face upwards. On top of each digging disc, and within its rear half, is a 500 mm diameter disc with its concave face downwards; this serves to transfer the ridge material to the following apron and to prevent sticky soil from accumulating on the digging disc. Compared with a conventional, flat, two-row share, the disc share assembly suffered virtually no blockages, gave better ridge transfer to the apron, required no more than one third of the drawbar pull (sometimes as little as one eighth) and was able to work satisfactorily in wet soil conditions. (As far as is known, this type of share has not yet been fitted to any commercially-available harvester).

Removing the soil

Most potato harvesters use a gently-sloping moving "apron" to remove the soil and convey the potatoes. Traditionally, this apron has been made up of a series of parallel steel rods, suitably bent and hooked over each other at both ends. Particularly in the more abrasive, sandy soils, there is an extremely high rate of wear where the linked ends of the rods rub against each other. Sometimes aprons start breaking as a result of this wear after only about 15 hectares. Some aprons are now constructed by attaching the rod ends to heavy-duty belts.

The apron is supported at both sides on rollers or sprockets, the shapes and sizes of which may be chosen to impart to the apron whatever degree of vertical agitation may be needed to cause the soil to pass through the apron. Too much agitation will, however, result in damage to the potatoes — particularly if most of the soil has passed through the apron well before the potatoes are discharged from it.

In recent years, many investigations have been carried out, in various countries, into the factors which influence soil-removal efficiency and the tuber-damaging potential of aprons and similar soil separating devices: much of this work has been summarised conveniently by McRae (1983). Let it first be stressed that, whatever effect the machine may have, the amount of damage sustained by the potatoes will be quite strongly influenced by tuber variety and size, soil type and condition, and soil temperature. Attempts to improve the efficiency of substantially conventional aprons have included investigation of the following possibilities.

- More convenient regulation of apron speed, sometimes achieved automatically in response to continuous sensing of the weight of material on a section of the apron.
- Continuous display to the operator of the ratio between apron speed and forward speed (it having been shown in some trials in England that where 2% of potatoes suffered severe damage at a ratio of 1.2:1, 7% and 13% suffered at ratios of 1.4:1 and 1.6:1 respectively).
- Easy alteration of the proportion of the apron length which is subjected to conventional, vertical agitation.
- Use of two aprons, one within the other, the inner apron having rods at "normal" spacing while the outer one has rod spacing 1.6 time as much and lifts the bigger, more damage-prone tubers away from the soil and smaller tubers with little or no agitation.
- A change of cross-section shape of the apron rod. When potatoes were dropped 150 mm on to the common 5 mm radius round-section rod, 20% were severely damaged and 10% bruised. Only 1% were severely damaged and 2% bruised when they were dropped the same distance on to a rod which presents to the potatoes a surface 22 mm wide with a 16 mm radius of curvature.
- Agitation of an apron in a substantially horizontal plane has been shown to result in less tuber damage and greater soil separating efficiency than occurred with conventional, vertical agitation. (A soil separating sieve was used instead of the conventional apron on some diggers in the late 1940's and early 1950's. However, it was very difficult to counterbalance the oscillation of a sieve; the more so when the weight of material passing over it was subject to wide variation.)

Separating stones and clods

Some soils naturally contain stones, with a sometimes bewildering range of types, sizes, shapes and numbers. The likelihood of clods occurring in potato fields at harvest time is associated with the soil type and moisture content, and with the care which has been shown in managing soil and crop up to the time of harvest. Where stones and/or clods are present when potatoes are harvested, any of four basic strategies may be selected for their separation.

- Manual separation on a moving conveyor. Several studies have been made of the effects of such factors as density of mixture on conveyors, speed of conveyors, placing of pickers relative to conveyors, whether pickers should select potatoes or rubbish, and manner in which selected material is moved (e.g. pushed sideways, or lifted).

- Manual separation, but with preliminary mechanical separation into two streams, one predominantly potatoes and the other mainly rubbish. Many commercially-available machines use an adjustable inclined conveyor to achieve the preliminary separation; the generally rounder potatoes rolling down-slope while the often flatter stones or irregular clods are carried up or across the slope.
- Automatic separation. The mixture of potatoes, stones and clods is marshalled into a layer one particle thick on a conveyor belt. The resultant "curtain" falling off the end of the belt towards a series of deflector fingers is scanned by a series of beams of weak X-rays or gamma-rays. Where scanning beams are interrupted by stones or clods, the corresponding fingers are released to allow the rubbish to fall to a reject conveyor. Each finger is returned rapidly to its normal position to deflect potatoes onto their conveyor. This device, developed by the NIAE and first demonstrated publicly in 1963, was first marketed as a stationary "in-store" version in 1967 but did not become available on a harvester until about 1970. Two machines of this type are believed to be operating in New Zealand.
- Separation in the store, where more efficient organisation of manual or automatic separation should be possible and where working conditions for the operators should be much more comfortable. It should then be possible to use an "unmanned" harvester, especially if stone-windrowing techniques have been used when planting, and clod development has not been excessive. But a word of warning! Where stones or clods are present among the potatoes during loading, transport and unloading, it is logical to expect a greater incidence of tuber damage.

Delivering harvested tubers to transport

The movement of tubers through the harvester and their final delivery into a suitable "transport container" is certainly worthy of comment. The potato tuber is so easily damaged that a drop of only 100 mm to 150 mm on to a hard, unyielding surface is sufficient to cause bruising or scuffing. Any impact, resulting from a change in direction or speed, is likely to cause damage. The risk of damage within the harvester will also be aggravated if tubers are allowed to roll significantly on conveyor aprons.

Potatoes having survived the various treatments given to them within the harvester, will usually end up in one of four positions:

- in bags, which may have been weighed and sewn up;
- in pallet bins;
- in a holding bin which is part of the machine;
- in a truck or a tractor trailer, travelling alongside the harvester.

If the tubers are bagged or binned they will probably be transferred (with due care to minimize damage) at the headland on to transport well suited to take them to market or to storage. When considering transport containers, in the context of damage to tubers, we must remember the risk of damage resulting from "static stress", in addition to the "dynamic stress", of impact between tuber and machine component. With pallet bins, for example, the use of plywood allows a perfectly smooth inner surface to be obtained. But if bins are made from spaced wooden planks care must be taken to suitably shape the planks, to ensure that tubers cannot be pressed against any hard, abrupt edges.

Considerable skill and care are essential in the efficient transfer of potatoes from a moving harvester to a vehicle travelling alongside. Tubers must be transferred gently into the vehicle, so the delivery conveyor must reach down to within 100 mm of the vehicle floor when loading starts. This means that the conveyor is exposed to the risk of serious damage if there is, though inattention or accident, any loss of synchronization in the progress of harvester and vehicle.

With due regard to their other duties, neither the harvester driver nor the pickers riding on the machine can be expected to maintain efficient visual monitoring and manual control of delivery conveyor height. One device has been described, whereby the driver of the transport vehicle is able to control the height of the conveyor: this entails a radio link between the transport vehicle and a hydraulic control valve on the harvester. Automatic control of delivery conveyor height can also be arranged with a system developed by the SIAE. The conveyor mounting incorporates a break-away release to minimize damage sustained through collision with the vehicle.

Transport from field to store

Quite often, the ground surface during potato harvest is sufficiently firm and dry for ordinary trucks to be driven fully laden across the fields without any difficulty. Multiple passes of transport vehicles along headlands and near gateways may, however, result in so much compaction of the soil as to create serious problems in the later use of cultivation implements.

Potato growers on heavier soils in regions subject to even moderate rainfall at harvest time must be prepared for the problem of transport vehicles becoming stuck, either through sinking into soft ground or through excessive wheelslip on ground which may be quite firm underneath but is greasy and slippery on top. Outstanding improvement in traction can be obtained by arranging a mechanical or hydraulic drive from the tractor to the trailer wheels. A similar technique can be employed to greatly improve the manoeuvrability of a tractor with trailed harvester. Harvester traction problems can also be minimized by reducing the tractive force demanded by the digging shares.

A vitally important aspect of the efficient transport of harvested potatoes is careful planning to ensure that the harvester is never kept idle for want of a container to receive its output. This calls for attention to:

- capacity and number of vehicles;
- distance from field to store;
- speed which can reasonably be maintained (which will be influenced by topography and roughness of the route);
- turnround time at store (unloading rate of vehicles, capacity of in-store conveying and handling facilities, vehicle manoeuvring space).

At the same time, all reasonable steps must be taken to make sure that the potatoes are not damaged during transport and handling. This calls for careful attention to such questions as:

- roughness of travel route;
- detailed design of vehicle unloading mechanism and in-store handling equipment.

CONCLUSION

Advances in mechanization have brought potato production to the point where little manual labour is really necessary, provided that the operation is on such a scale as to be able to carry the very considerable investment burden for capital equipment, much of which is inapplicable to other crops.

With the possible exception of potatoes grown for the production of alcohol or starch, the most important single consideration in the design, selection and management of potato machinery is the prevention of tuber damage. An excellent review of the incidence, assessment and control of damage is given by McRae of the Scottish Institute of Agricultural Engineering in "Mechanical Handling Damage", a 60 page document published about 1980 for the Marketing Policy Committee of the Central Council for Agricultural and Horticultural Co-operation.

Advances in technology, both biological and electronic, may have far-reaching effects on potato mechanisation.

Planting methods and equipment could be completely revolutionized through the use of true potato seed or very small tubers, with a resultant thousand-fold reduction in the weight of propagating material! But many practical problems will have to be resolved before this approach is likely to have a significant influence on commercial potato growing.

Many harvesting difficulties would disappear if a "top-pull" approach to harvesting could be developed to a commercially-acceptable stage. An experimental machine which loosened the ridge with an under-running share and gripped the tops to lift the tubers has been demonstrated. Commercial acceptance of this harvesting principle would be critically dependent on the breeding of varieties in which tubers were retained firmly on the stolons up to maturity, and the discovery of a suitable means for ensuring that the keeping quality of the tuber was not impaired by the wound resulting from separating the tuber from the stolon.

Mention has already been made of the outstanding way in which electronic technology has been applied to potato planting and harvesting. Of possibly greater long-term significance are the applications to sizing and quality grading of potatoes, which have already been introduced by some manufacturers. One size-grader uses 24 photo-electric cells to assess the volume of each tuber, with separation into six size categories. Several quality graders have been developed, wherein an operator touches each reject tuber on a conveyor belt with a special pointer (or, in some cases, touches its image on a television screen). Each tuber so identified is automatically ejected as it leaves the conveyor.

Finally, housewives' buying habits and preferences are bound to have some influence on what goes on in the potato field and the potato store!

REFERENCES

Anon. (1977) SIAE powered ridger goes commercial. *Power Farming July 1977:* 67.

Anon. (1982) Pre-harvest haulm puller. *Power Farming September 1982:* 15.

Anon. (1983) The computer-controlled Setronic planter. *Power Farming April 1983:* 14-15.

Fussell, G.E. (1952) *The Farmers Tools.* Andrew Melrose, London: 186-190.

McRae, D.C. (1983) Better harvester design. *The Agricultural Engineer 38:* 42-45.

NIAE (1948) Test of Dolle automatic potato planter. *Agricultural Engineering Record 2:* 224.

Witney, B.D. (1981) Effect of stone and clod windrowing on potato production techniques (summary). *Potato Research 24:* 211-212.

Witney, B.D. (1982) Stone windrowing techniques. Paper to Engineering Section, European Association of Potato Research, at Penicuik, October 1982.