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Institution of Agricultural Engineers
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Contents

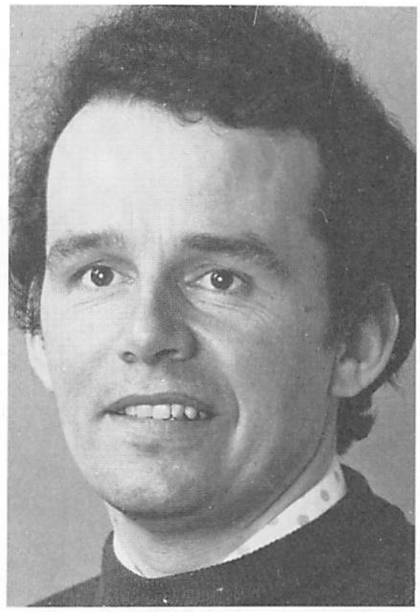
Three categories of paper appear in the Journal:—

a) Papers submitted to the Honorary Editor and subsequently refereed.
b) Conference papers not generally refereed but which may be if the authors so request and if the refereeing process can be completed before the Conference Report is due to be published.
c) Mechanisation and review articles not normally appropriate for refereeing.

Cover — Reciprocating share undercutter-lifter for vegetables grown in beds — *see pages 119-120.*

Tractor safety on slopes

A G M Hunter



Summary

THE continuing number of tractor overturning accidents on slopes can be reduced now that their causes are better understood. Research at the Scottish Institute of Agricultural Engineering (SIAE) has established the primary causes as stability loss and control loss. Safer working practices could be introduced by training tractor drivers, developing safety aids, and designing safer machines for slopes.

1. Introduction

TRACTOR safety on slopes concerns most farmers because nearly all farms have sloping land, and overturning accidents can occur on quite moderate slopes. The risk of the driver being killed when his tractor overturns has certainly been reduced by compulsory fitting of safety cabs but a residual number of deaths remain[1,2], and the risk of injury is high. The annual number of overturning accidents shows no sign of dropping, and each one costs money because the tractor is a major investment which may be written off or need expensive repairs and there are further losses due to interruption of working.

The underlying causes of overturning accidents on slopes are not affected by fitting tractor safety cabs so these causes must be tackled in any attempt to reduce the accident numbers. The first step which has been developed to an advanced degree at SIAE by Spencer is that of understanding the causes. His work, which is now well known, is based on mathematical modelling with the results presented in the form of polar diagrams[3]. Analysing a selected number of actual accidents using the polar diagrams has given a clear insight into the particular types of overturning accident which must be guarded against[4]. They can all be classed as stability loss accidents, where the tractor overturns directly, or control loss accidents, where the tractor slides downhill before overturning. These accidents can be avoided and their numbers can be reduced by following three main approaches: training tractor drivers; developing safety aids; and designing safer machines for slopes. The purpose of this paper is to show how these approaches are related through research work. The sections which follow summarise the current state of research knowledge on overturning accidents, and illustrate ideas for accident reduction.

2. Study of accidents

2.1 Stability and control loss

A considerable amount of information on overturning accidents is contained in the accident records compiled by the Health and Safety Executive, who kindly made them available for study purposes. Two surveys[5,6] of these records identified the main causes of tractor overturning accidents as stability loss, control loss, speed or rough ground, driver's misjudgement and miscellaneous. Accidents on silage clamps, and road traffic accidents were excluded from the surveys. From the above list, accidents due to speed or rough ground are now considered to be special cases of stability loss accidents.

The distinction between stability and control loss accidents and driver's misjudgement accidents should be clarified. Driver's misjudgement is the cause of an accident when the outcome is clearly predictable, for example when a tractor is driven into a ditch, but most accidents on slopes are not predictable simply on the basis of the driver's judgement. Even long tractor driving experience is not sufficient to predict when the stability or control limit has been reached.

Stability loss and control loss accounted for two-thirds of all reported tractor overturning accidents. Nearly 90% of stability and control loss accidents occurred on slopes compared with less than half of other accidents. Also 80% of control loss accidents in England and Wales, and 70% in Scotland, occurred on grass.

2.2 Polar diagrams

The purpose of theoretical work has been to analyse the conditions when a tractor will lose stability or control. The basic assumptions are that the tractor is being driven steadily along a heading angle, α, relative to the uphill direction on a slope of angle β. With this convention, when $\alpha = 90°$ the tractor is being driven across the slope, and when $\alpha = 180°$ the tractor is being driven down the slope. It is also assumed that a single friction coefficient can be used for computing grip under braked wheels, and a single rolling resistance coefficient for computing rolling resistance at unbraked wheels.

Because the front axle beam is pivoted under the body of the conventional tractor, the vector force equations used to determine tractor wheel loads are very complicated. The solution to these equations is computed in order to find the slope and heading angle points at which stability or control will be lost. The locus of these points forms the stability boundary and control boundary shown on a polar diagram. When operated outside the stability boundary the tractor will be unstable and when outside the control boundary the tractor will be out of control. The wide application of polar diagrams to cover many different types and combinations of farm machinery has been described in an SIAE technical report[7].

The polar diagrams arise from theoretical work but this has been supported by full-scale experiments using a radio-controlled tractor (fig 1), which was built under contract to the Health and Safety Executive. The tractor has been used mainly for sideways stability loss experiments and downhill control loss experiments[8]. The calculated values of critical slope agree closely with those measured where the radio-controlled tractor overturned or slid downhill. With direct experimental confirmation of values shown in the polar diagrams it is possible to use them confidently for establishing safe methods of working on slopes, a subject which will be referred to later.

3. Research evidence

Some of the ideas relevant to safe methods of working on slopes will now be described. Each of these ideas is based on research evidence. The sections which follow are not intended to be fully comprehensive but to give a broad picture of several important conclusions.

3.1 Grass grip

The variable which has the most direct effect on tractor control loss is the grass grip under the tractor tyres. As already explained most control loss accidents happen on grass. Grass is much more slippery than soil because the tractor tyres do not penetrate the turf, but clog with grass as soon as they start to slide. The friction coefficient is then determined not primarily by tyre rubber on grass but by grass on grass. Under most grass conditions the grip is low enough for the tractor to start sliding downhill under its own weight on a slope which is not steep enough for the tractor to overturn statically. The tractor may start to slide when facing along any heading angle, not only when facing downhill.

Once a tractor has started to slide there is very little that the driver can do to recover the situation; he may attempt to

A G M Hunter BA CEng MIMechE is of the Equipment Behaviour Section, SIAE (Refereed Paper).

Fig 1 Radio-controlled tractor on point of overturn during full-scale experiment

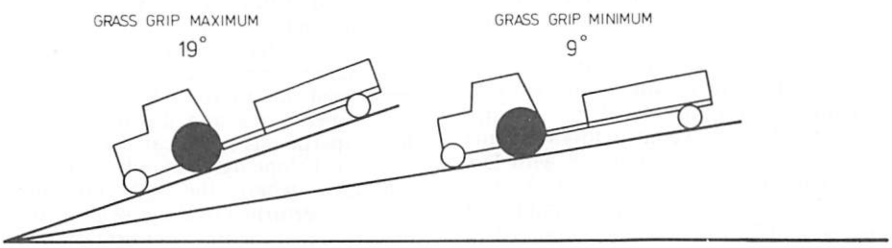


Fig 2 Example of measured values of critical descent slope for 2-wheel drive tractor with trailer. Variation from maximum to minimum grass grip due solely to changes in grass conditions

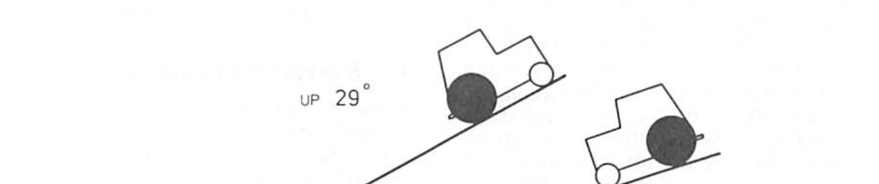


Fig 3 Example of computed values of critical ascent and descent slope for 2-wheel drive tractor. Variation due solely to tractor heading angle. (A tractor may slide on slopes much less than those shown when the grass is more slippery.)

drive forwards out of the slide but this is not practicable if the ground ahead is steeper or if there is an obstacle; he may attempt to turn immediately across the slope but this could result in the tractor slewing right round and continuing to slide backwards, or in the tractor overturning during his turn. Whenever a tractor starts to slide on grass the situation is dangerous.

The slope on which a tractor starts to slide, known as the critical slope, has a wide range of values determined by the grass grip under the tractor tyres. The range estimated from experimental measurements on level ground is from 11° to 22° for a two-wheel drive tractor alone and from 9° to 19° for a two-wheel drive tractor with loaded trailer, as shown in fig 2[9]. The grip changes due to factors such as rain, dew, hardness of the ground, grass growth and type of sward but these changes are unpredictable and it is not possible to estimate the critical slope for control loss by observation, even with experience.

3.2 Heading angle

Polar diagrams clearly show that the stability boundary and control boundary are dependent on heading angle. The implications of this are of direct concern to the tractor driver. The most straightforward example is one which occurred early in the SIAE research work when a two-wheel drive tractor was driven to the top of a grass field where it had been driven many times before. When the tractor was turned to face downhill it started to slide immediately and gather speed. The driver only escaped a very serious accident because the lower part of the field was less sloping so that the tractor slowed down again[10]. Because the control boundary is at a greater critical slope for driving uphill than downhill, the tractor can be driven up a slope where it is out of control coming down, as illustrated by fig 3. The reason that no accident had occurred previously was that the grass grip was previously greater and hence the control boundary was outside the range of slopes in the field.

In addition to driving directly uphill it may be possible to drive the tractor within the control boundary on almost all heading angles other than directly downhill. In particular the control boundary at $\alpha = 90°$, directly across the slope, usually determines the maximum critical slope for control loss. This means that it is possible to drive a tractor across a slope without sliding where it will slide immediately if faced uphill or downhill. There is no room for manoeuvre in such a situation. This example clarifies the difference between critical slope, represented by a point on the control boundary, and safe slope. It is debatable whether any slope greater than the critical slope for $\alpha = 180°$, directly downhill, can be described as safe even though the tractor may be driven up or across it without sliding.

3.3 Four-wheel drive

The major difference between a 4-wheel drive tractor and a 2-wheel drive tractor, relevant to safety on slopes, is that the former has engine braking on the front wheels when driven downhill. Thus the control boundary for a 4-wheel drive tractor is not influenced by heading angle, and a 4-wheel drive tractor driven without trailed equipment will have the same grip at all heading angles. The 4-wheel drive tractor can therefore be driven more safely on steep slopes than the 2-wheel drive tractor.

However, using the 4-wheel drive tractor is not an infallible safety measure for three reasons. Firstly, the slope on which the control boundary or stability boundary is exceeded will be very steep and the resulting accident will be very severe, amply illustrated in fig 4. Secondly, the 4-wheel drive must be engaged otherwise the tractor will lose control downhill on the same slope as a 2-wheel drive tractor. Thirdly, trailed equipment reduces the critical slopes for a 4-wheel drive tractor by a large amount, just as for a 2-wheel drive tractor. A trailer, dung-spreader, slurry tanker, or any other trailed equipment may push or pull the tractor downhill or it may itself overturn taking the tractor with it.

Fig 4 Extensive damage to 4-wheel drive tractor after multiple roll on very steep slope (Photograph reproduced by courtesy of the Health and Safety Executive Agricultural Inspectorate).

Fig 5 Example of computed values of critical descent slope for 2-wheel drive tractor and slurry tanker both with and without brakes

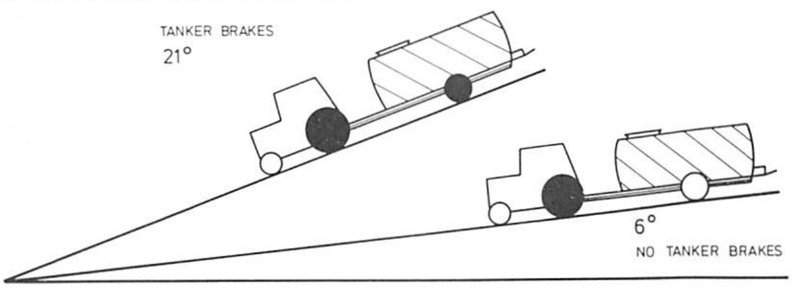


Fig 6 Tractor with outrigger to simulate the weight of a mounted rotary mower. During cornering at speed the tractor would have overturned except for the outrigger wheel

3.4 Trailer brakes

The critical slope for direct downhill control loss is greater when brakes are used on trailed equipment than when they are not used. During early research work on trailer brakes it was apparent that brakes were effective on grass slopes as well as on level roads, so fitting and using trailer brakes is a valuable safety measure[11]. The increase in critical descent slope may be large depending on the weight and balance of the trailed equipment. In fig 5 a calculated increase from 6° to 21° is shown for a heavy slurry tanker which has its wheels positioned so that only 9% of the filled weight is transferred to the tractor drawbar[12]. Such a large increase reflects the fact that trailer brakes are most effective when the trailer is heavy relative to the tractor, 3.4 times the tractor weight in this example, and the trailer is balanced or nearly balanced on its own wheels[13].

Four-wheel trailers are one example where the trailer is completely balanced and trailer brakes are essential. Forage harvesting equipment with the forage harvester and trailer drawn in line behind the tractor is another example where the trailed equipment is balanced and may be 3.5 times the weight of the tractor[14]. In this latter case brakes may be unavailable or inconvenient to use but without them the tractor may be pushed downhill on any slope above 6° (10%). The use of brakes does not contribute to tractive force for driving uphill so, although brakes allow safer working on slopes, they do not necessarily allow working on steeper slopes.

3.5 Cornering

When a tractor is driven at speed while cornering there is a marked effect on the tractor stability. The dynamic stability boundary is offset relative to the static stability boundary due to centrifugal force on the tractor. The tractor may overturn on slopes that are considerably less than for static conditions. The most striking example of this is in a hay or silage field where the tractor is often driven round in a loop turn at the headlands in order to maintain a neat rectangular swath pattern. During experimental work using a tractor with outrigger to simulate the weight of a rotary mower, fig 6, the tractor wheel lifted on a slope of only 2° at a speed of 18 km/h (11 mile/h)[15]. Other experiments using the tractor with a mounted hay tedder showed that a high cornering speed was sufficient to overturn the tractor even when the mounted load was not offset[16].

4. Accident reduction

The scope for reducing the number of tractor overturning accidents and for improving tractor safety on slopes is considerable. As a result of research it is possible to see much more clearly how this should be done. In addition to continuing research work there are opportunities in three areas: training, safety aids, and safer design.

4.1 Training

Tractor safety on slopes is a subject which tractor drivers have in the past been expected to learn by experience. This puts the driver unnecessarily at risk. The principal causes for accidents on slopes, stability and control loss, arise in a wide variety of circumstances: tractors alone, tractors with mounted equipment and trailed equipment, on steep slopes and on gentle slopes. This complex subject should properly be taught in the classroom so that these varied circumstances can be appreciated and preventive measures can be thought through in safety. When the tractor driver works on slopes he can then ensure that all his actions are well-considered.

An ideal teaching aid is a classroom model slope used for demonstrating tractor accidents, fig 7. In a simple and convincing way the model can be used both for lecturing and discovery learning about almost all types of stability and control loss accidents. A full description of both the construction and use of this model is contained in a technical report[17]

4.2 Safety aids

In addition to training in the ideas of tractor safety, the driver can use a

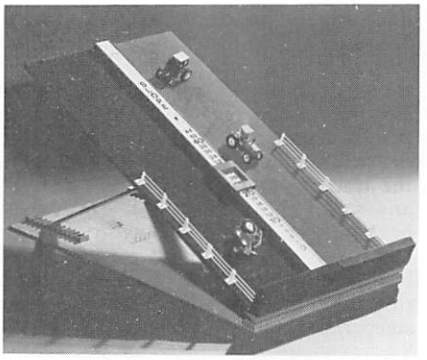


Fig 7 A classroom model for demonstrating tractor accidents on slopes

number of safety aids when working on slopes. One example is the weight transfer hitch used with trailed equipment which can improve the braking force at a tractor rear wheels. Another example is a set of tractor wheel chains of the forestry type which are very effective on grassland in penetrating the turf to obtain considerably more wheel grip than the tyres alone. The wheels of a tractor can be set at their maximum track width to improve stability compared with the normal track width which is often the minimum.

A safety aid for predicting when it is unsafe to drive on a slope also has potential. One such device under development gives an estimate of the critical descent slope in a field after making braking measurements with the same tractor on a level part of the same field[18]. The device uses a pendulum decelerometer with associated electronics to give a direct readout of critical slope, and it is hoped that it will soon be developed to a commercial form.

4.3 Safer design

Few of the range of tractors and equipment currently on the market are designed with slope safety in mind. If slope safety were to be included in the manufacturer's design philosophy then the tractor driver could work in greater safety and the cost and time spend on recovering overturned tractors could be minimised. Some modifications are feasible without any major design changes. For example, fitting brakes as standard to all trailed equipment would be a major safety improvement. Designing tractors so that the wheel tracks can be adjusted more easily, and trailers so that the wheel tracks are adjustable, would improve stability. More radical design changes to produce four-wheel drive machines with exceptionally good stability for forage mechanisation on steep slopes have been adopted in some alpine countries[19].

There are a number of examples of recent developments where safety on slopes has been ignored. The use of rotary mowers at speed on slopes is less safe than using reciprocating mowers at slower speeds; front-mounted implements on a tractor bring the overall centre of gravity forward so that the tractor runs downhill out of control and overturns more easily; sprayer tanks are larger and mounted higher in order to give greater ground clearance over crops than previously, and are thus more liable to overturn.

5. Conclusions

The number of tractor overturning accidents remains high in spite of fitting tractor safety cabs because a cab, although it reduces the danger to life and limb of the driver, does not eliminate the accident causes. The overturning accident records show that the primary causes of accidents on slopes are stability loss, which is direct overturning, and control loss, which is sliding bodily downhill before overturning. The SIAE research, through mathematical analysis and full-scale experimental work, has determined the precise circumstances under which accidents occur.

Some typical findings from this work are that the slope on which a tractor starts to slide bodily downhill out of control is determined primarily by the grass grip under the wheels, which varies continuously over a wide range of values- the direction in which a tractor is driven on a slope, whether up, down or across, directly influences the stability and control of the tractor; a 4-wheel drive tractor, because of its engine braking on the front wheels when travelling downhill, is safer than a 2-wheel drive tractor on slopes; work with trailed equipment on slopes is safer if the trailed equipment has brakes; and when cornering on slopes the tractor speed should be kept low because centrifugal force markedly reduces the stability of a tractor.

The problems of stability and control of tractors on slopes are familiar to tractor drivers but the subject is complex and the explanations for these problems are not self-evident. The tractor driver could work more safely on slopes if he was taught in the classroom about accident causes and safety measures as well as learning them in the field. There is now sufficient material and a visual teaching aid for this purpose. The range of safety aids available to the farmer, such as trailer brakes, should be extended to include measurement devices which help the driver to predict, before he drives onto a slope, the point at which his tractor might overturn or slide downhill. Work at SIAE is already well advanced towards this end. As new tractors and machines are developed the problems of slope safety should be considered. The analytical techniques which are now available could be used by manufacturers at the design stage. There is now a sufficient pool of knowledge for the numbers of tractor overturning accidents on slopes to be reduced. The need is for this knowledge to be applied widely in practice.

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A study of energy saving equipment for farm dairies

Hugh M Shepherd

Introduction

ENERGY costs are rising annually. Decreasing world reserves indicate that in the near future costs may rise even more dramatically. These are compelling reasons for a critical examination of the efficiency of fuel utilization and the adoption of any economically viable means of minimising energy requirements. But any energy saving method or device must give as good a return on capital as would be possible by that investment elsewhere in the business.

By 1975 all off-farm sales of milk to the Milk Marketing Boards in Scotland were handled in bulk. Producers had to provide bulk milk tanks for on-farm storage with the necessary equipment to comply with the current regulations for cooling and storage. Most farms at that time had single phase electricity supplies, limiting the size of electric motors; hence the widespread use of indirect refrigeration bulk tanks. In nearly all cases air cooled condensers were used in which heat extracted from the milk was lost to the atmosphere.

In 1980-81 total sales of milk off farms to the Milk Marketing Board in Scotland were 1242 million litres. Milk stored in bulk must be cooled to less than 5°C requiring a reduction in temperature of approximately 30°C. In total this represents an annual energy value of 43.3 million kWh of electricity. It is virtually impossible to save all this energy but two systems are commercially available which are designed to reduce this loss. One is designed to reduce the energy input necessary for cooling and storing the milk while the other involves reducing power required for water heating by transferring heat extracted from milk during the cooling process. The former is referred to as pre-cooling and the latter, heat recovery. The objective of this project was to evaluate both systems to show the amount of energy saved and the return on capital invested in an actual farm situation.

Pre-cooling

THIS system (fig 1) is designed to reduce the temperature of the milk prior to storage in the bulk tank. Milk is pumped from the receiver vessel of the milking installation through a plate heat exchanger and thence to bulk storage. Cooling takes place in the heat exchanger by means of water passing across every alternate plate in the opposite direction to the milk flow. Milk outlet temperature depends on inlet water temperatures and water-to-milk flow ratio; the latter can be controlled by an adjustable restrictor valve on the milk delivery pipeline. The number of plates on the exchanger can be varied to suit any milk flow rate.

The pre-cooler used was an Alfa Laval JPC 3V comprising a 200 litre stainless steel balance tank and a 27 plate heat exchanger. A solenoid valve was fitted to the water supply which was controlled in parallel with the milk pump through the liquid level control box. This arrangement allowed cooling water to flow only when milk was being pumped through the cooler. A gate valve was used to cut off cooling water during plant cleaning and a drain valve enabled the removal of water from the pre-cooler prior to plant cleaning. A milk flow control valve and a filter were located between the milk pump and the plate heat exchanger.

Cooling water was taken directly off the mains supply and after passing through the cooler was stored in a 3600 litre header tank. The controlled water level in the header tank was lowered to ensure sufficient storage capacity for all of the cooling water. The wide variation in mains water pressure made it necessary to fit a pressure regulating valve in an attempt to stabilise water-to-milk ratio for the purpose of the trial.

Heat recovery

This system (fig 2) is designed to transfer heat normally lost to the atmosphere from the air cooled condenser of the refrigeration unit. The heat is transferred from the refrigeration gas to a water supply by a heat exchanger unit, providing warm water for use in the dairy.

Various designs of heat recovery units (HRU) are now available. The type used for this project comprised an insulated copper water tank into which was fitted an 18 mm diameter copper coil. Hot refrigeration gas passing through the coil raised the temperature of the surrounding water. The temperature rise in the water depended on the pressure of the refrigeration gas in the system. In this particular trial no pressure control valves were used.

The HRU used in the trial was a Fullwood, model HRU 60 with a capacity of 270 litres. When in use the HRU fed an acidified boiling water boiler for milking plant cleaning and a smaller boiler for udder washing. Both gas and water pipes were wall lagged.

By-pass valves were not fitted to the refrigeration gas lines because of claims that their inclusion tended to increase compressor running time and also increased the risk of compressor damage due to increased head pressure.

Milk was stored in a Fullwood, 2270 litre Dari-kool tank with indirect refrigeration. The Prestcold refrigeration unit with air cooled condenser was powered by a 1.5 kW electric motor. The bulk tank and refrigeration unit was checked by a specialist at the start of the trial.

The trial was conducted in the College dairy at Craibstone Farm, Bucksburn, Aberdeen.

Watt meters were installed to record the respective power consumptions of the milking plant cleaning boiler (acidified boiling water cleaning), the udder washing water heater, the compressor and the bulk tank.

Kent flow meters were used to record the volume of water used for udder washing, plant cleaning, cooling water for pre-cooling, and overflow from the header tanks.

Water temperature was recorded at the inlet and outlet of the heat recovery unit, the udder wash boiler and ABW boiler, while milk temperature was recorded at inlet and outlet of the plate heat exchanger. Three channel Chessell thermograph recorders were used giving a continuous recording which not only gave the required temperature records but also the approximate time scale of temperature changes.

Procedure

During the first four months of the trial from July to November the installation was running as normal with neither energy saving system being used in order to obtain standard data over a reasonable period of time. Thereafter, trial periods of varying duration for heat recovery, pre-cooling and normal use were recorded.

Hugh M Shepherd SDA NDAgrE TEng(CEI) MIAgrE is of the North of Scotland, College of Agriculture, Aberdeen.

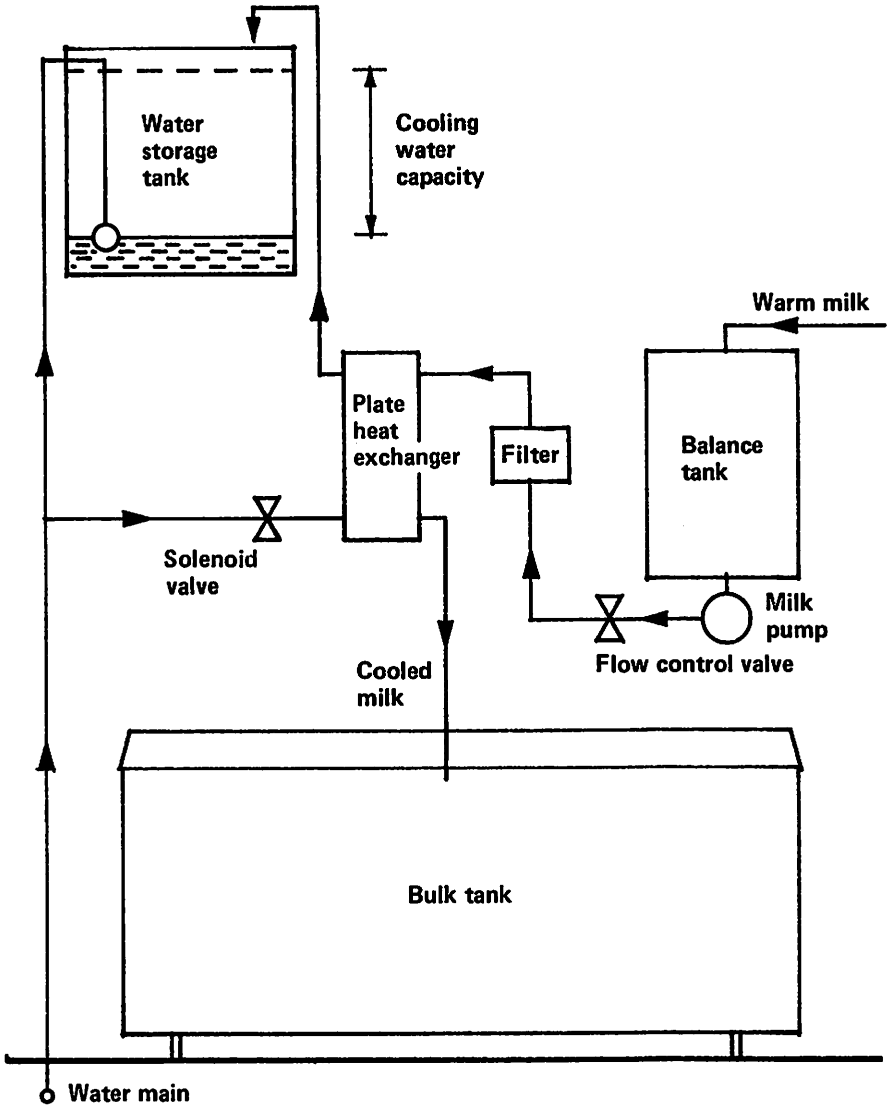
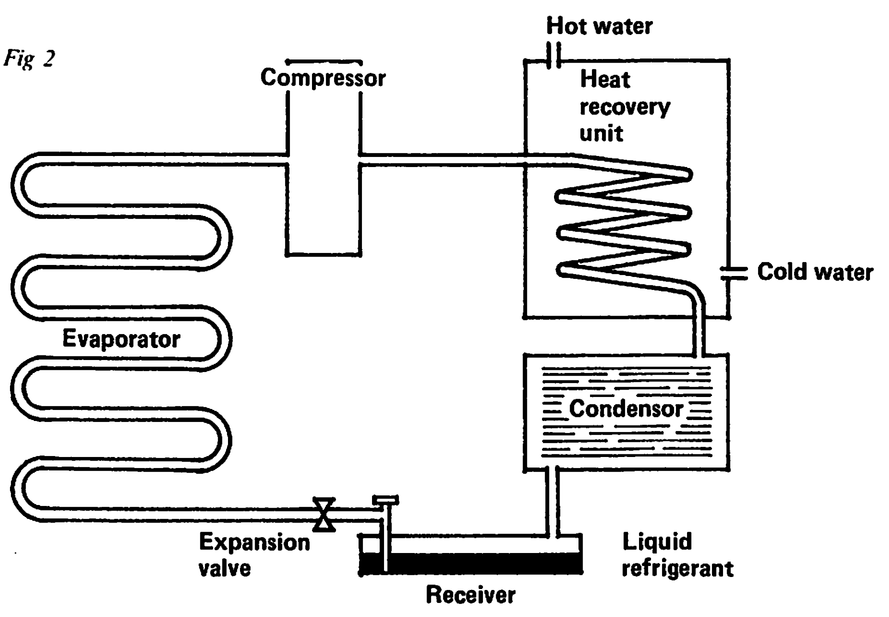


Fig 1

Diagram of pre-cooling system

Fig 2



Schematic layout of heat recovery unit

To begin a trial run the required system was connected and allowed to run for one day before readings were taken, so that residual effects of the previous system operating were eliminated. All the meters were read at mid-day. The milk yield during trial periods was obtained from the Milk Marketing Board's collection tanker print out.

Several test periods had to be abandoned for various reasons, including failure of the refrigeration control, a failed solenoid valve, and a leaking heat recovery unit which had to be replaced.

Lack of complete control of events in the trial inevitably resulted in some readings which could not be easily explained. However, over the 30 month period of the trial sufficient data has been collected to give reliable results upon which this report is based.

Results

The amount of energy saved by pre-cooling was determined by recording the amount of milk cooled per unit of electricity (kWh) with and without pre-cooling in operation. Table 1 summarises the amount of milk cooled under normal conditions, ie without pre-cooling. Variations occur but as would be expected the cooling performance is better in the colder winter months.

Table 2 shows the milk cooled per kWh with pre-cooling in operation. Temperature of the cooling water and water to milk ratio can affect the cooling performance considerably but over a year the average in this case was 154 litres of milk cooled per kWh.

The best overall performance was recorded when pre-cooling and heat recovery were operating simultaneously. Only one test period with both systems in operation was recorded due to difficulties of airlocking caused by insufficient pressure when water in the header tank was at its lowest level. The controlled head of water had to be lowered in order to provide sufficient storage capacity for the cooling water.

The total milk production for 1980-81 was 699 238 litres. Table 3 shows the annual cost of cooling for the two systems.

Tables on next page

The saving in cooling costs in this particular instance was £517. The average number of cows in milk for the year 1980-81 was 102.3 giving an annual saving per cow in milk of £4.30.

Energy saved by heat recovery

Without having two identical systems side by side, one using heat recovery the other not, it is impossible to arrive at a precise value of energy saved. In the case of the udder wash boiler such variables as inlet water temperature, ambient temperature and volume of water used through the boiler, particularly on occasions when water is drawn off faster than the heating element can maintain the preset temperature, all combine to cloud the issue.

Assessment of savings made by heat recovery in the udder wash boiler was made by subtracting the actual power used from the calculated power required taking into account boiler efficiency.

Table 1 Milk cooling — no pre-cooling

Period	*Bulk tank*	*Compressor*	*Total*	*Milk yield*	*Milk cooled per kWh*
	kWh	*kWh*	*kWh*	*litres*	*litres/kWh*
1978					
14 Jul – 29 Nov	553	5357	5910	234389	40
17 Jul – 31 Jul	36	449	485	21216	44
25 Oct – 7 Nov	63	589	651	28501	44
22 Dec – 10 Jan	59	612	671	39426	59
1980					
13 May – 29 May	56	750	806	33629	42
20 Jun – 9 Jul	60	824	884	47151	42
7 Sept – 23 Sept	58	783	841	35005	42
Average performance					42

Table 2 Milk cooling — with pre-cooling

Period	*Bulk tank*	*Compressor*	*Ratio water/ milk*	*A V mains water temp*	*Milk cooled per kWh*
	kWh	*kWh*		*°C*	*litres/kWh*
1978					
30 Nov – 13 Dec	14	226	1.5:1	7	111
1979					
29 Jan – 26 Feb	27	265	1.6:1	3	177
19 Mar – 26 Mar	3	72	2.4:1	3.5	183
2 May – 9 May	7	86	2.2:1	7.5	144
26 Jun – 16 Jul	26	375	1.9:1	13	94
28 Aug – 3 Oct	72	604	2.8:1	12.5	89
9 Nov – 5 Dec	27	244	2.6:1	5	194
1980					
11 Jan – 30 Jan	5	80	2.4:1	4.5	457
30 Jan – 14 Feb	3	47	2.5:1	5	561
9 Mar – 24 Apr	15	351	1.8:1	7	264
18 Jul – 20 Aug	24	380	1.5:1	13	84
24 Oct – 28 Oct	0	35	1.7:1	9	193
26 Nov – 28 Nov	1	11	1.9:1	7	341
Total	3010				
Average			2.1:1		154

Table 3 Alternative annual cooling costs

	Cooling rate		
	litres/ kWh	*kWh*	*£ **
Normal	40	17 481	699
Pre-cooling	154	4 541	182

** Electricity charged at 4p per kWh.*

Meters recorded the volume of water used, actual power used, and the thermostat was set at 50°C. The udder wash boiler efficiency was found to be 89%. Table 4 shows results from eight trial periods during which time heat recovery was in operation. The calculated total power was arrived at as follows:

$$\text{temp rise (°C)} \times \text{spec heat capacity (4180)} \times \frac{\text{volume (l)} \times \text{boiler efficiency (\%)}}{3{,}600{,}000} = \text{kWh}$$

Energy input derived from heat recovery is sometimes given as a percentage of the total theoretical power required. This figure can be distorted by so many variables that it has little meaning. A more reliable figure is the power input due to heat recovery per 1000 litres of water used.

The volume used for udder washing varied between an average of 1.7 l/cow day during the first year of the tests to 2.2 l/cow day during the second year. Taking an average of 2 l/cow day gives an annual consumption of 73,000 litres. The average energy input of 37.75 kWh/1000 litres by heat recovery represents a saving of 2756 units of electricity.

Energy saved by heat recovery in the acidified boiling water (ABW) boiler for plant cleaning was virtually nil during the early part of the trial because of a leakage which had nullified the boiler insulation. Eventually a new boiler was installed and as table 5 shows, its purchase was well justified.

Table 5 Energy input to ABW boiler derived from heat recovery

Test period	*Energy saved/1000 litres*
	kWh
May – Jul	28.3
Oct – Dec	22.9
Av	25.6

Consumption of water for plant cleaning was 120 450 litres per annum hence energy saved due to heat recovery was 3084 kWh.

Energy saved by heat recovery in both boilers came to a total of 5840 kWh.

Physical aspects of Craibstone Dairy Unit

Herd size varied between 120 to 122 cows during the trial but for the purpose of financial assessment a 120 cow herd, 80% of which will be assumed to be in milk at any one time, giving 100 cows milked per day. Annual milk yield varied between

Table 4 Energy saved by heat recovery in udder wash boiler

Trial period	*Udder wash water*	*Mains water temperature*	*Calculated total energy*	*Actual energy input*	*HRH energy input as % of total*	*HRU energy*
	litres	*°C*	*kWh*	*kWh*		*kWh/1000 litres*
1978						
20 Dec – 29 Jan	8342	3.5	506	243	52	32
1979						
18 Apr – 1 May	3039	7	171	46	73	41
12 Oct – 24 Oct	1645	10	86	21	75	40
6 Dec – 21 Dec	4074	5	239	81	66	39
1980						
18 Feb – 28 Feb	2434	5	143	55	62	36
30 May – 10 Jun	2093	11	107	21	80	41
11 Jul – 16 Jul	1491	13	72	12	83	40
29 Oct – 2 Nov	1171	9	63	25	60	33

661,852 litres and 699,238 litres over the period of the trial giving an average of approximately 680,000 litres per annum. The milking installation was cleaned using the acidified boiling water method. In this case 330 litres of water were used per day and the water was raised to 90° C. Mains water temperature ranged from 2° C to 14° C with an average temperature of 8.5°C. Udder washing water used varied between an average of 1.7 to 2.2 litres per cow each day. An average of 2 litres per cow per day is assumed for relevant calculations. The cost of electricity is taken as 4p per kWh.

Installation Costs (as at September 1981)

Pre-cooling	– Plate heat exchanger (cap 1125 litres/hour)	£ 504
	S/S balance tank (200 litres)	448
	Solenoid valve	63
	Flow control valve	121
		1136
	Estimated plumbing costs	300
	Total cost of pre-cooling system	1436
Heat recovery	– Heat recovery unit (capacity 270 litres)	£ 550
	Estimated plumbing costs	200
		750

On some farms a water header tank of suitable size may not be available and would be an additional cost for a pre-cooling system. Storage capacity above the controlled water level in the header tank should be a little more than the amount of milk produced per day.

Conclusions

The use of water to reduce the temperature of milk prior to bulk storage can substantially reduce the energy input required for cooling. Where water is available in quantity from a private farm supply it may not be necessary to recycle it but with the increasing cost of metered supplies cooling water must be reused, otherwise the benefits in running costs are greatly reduced.

Financial viability of pre-cooling depends very much on individual circumstances. The annual milk production in relation to initial cost is the most important factor. Round-the-shed and small parlour milking systems may not need a stainless steel balance tank which can almost halve the initial capital cost. Availability of an existing header storage tank of suitable capacity will also reduce capital cost. The results from this trial show a saving in cooling costs of £4.30 per cow per annum.

A substantial saving in energy input for water heating can be made by recovering heat from a refrigeration system. Initial capital cost is likely to be lower than for pre-cooling but the savings will also be less. Heat recovery will become viable on a unit of smaller size than pre-cooling, but pre-cooling will benefit more from economy of scale. Efficient utilisation of preheated water is essential for the system to be viable hence the need for really effective lagging. Results from this trial show an energy gain from heat recovery of approximately 25 kWh/1000 litres in the ABW boiler and 38 kWh/1000 litres in the udder wash water boiler.

Discussion

Care must be taken in the interpretation of these results in as much as they apply to one specific farm situation. With regard to pre-cooling the amount of energy saved will vary with:

a) volume of milk produced

b) temperature of the cooling water. During this trial mains water temperature varied between 1.9°C to 14.6°C. At water-to-milk ratio of 2.5:1 milk can be cooled to within 2-3°C of inlet water temperature hence milk produced during the winter months will require less refrigeration. Autumn calving herds therefore stand to benefit most from pre-cooling.

c) ratio of cooling water to milk. No attempt was made in this trial to find an optimum ratio but manufacturers suggest 2:1 in practice. Higher ratios give a greater drop in temperature but may result in water wastage.

Cooling water temperature gain depends on water to milk ratio but is unlikely to exceed 13°C. This could provide a useful saving if fed directly to the dairy boilers but the difficulties involved make it impractical. In this trial cooling water was stored in a 3600 litre header tank which supplied the entire dairy unit. By the time the cooling water mixed with water already in the header tank the eventual outcome was a mere 2°C rise in temperature on reaching the boilers. Claims have been made that providing cows with warmer drinking water in winter may increase consumption and result in higher yields. No attempt was made to quantify such a claim in this trial.

Up to 2:1 water to milk ratio was used during the summer months without water wastage. This may not be the case on every farm but if water wastage does occur it is simply a matter of matching supply to demand by maximising drinking opportunity when cows are in for milking and reducing water to milk ratio. If drinking water troughs in fields close to the steading can be fed from the header tank, so much the better.

Heat recovery units vary in size, design and efficiency of heat transfer.

Temperature rise depends to some extent on the pressure of gas in the refrigeration system but temperature increases of between 30° C to 40° C can be expected. However it is the efficiency of utilisation which plays the most important part in effecting savings by heat recovery. Water used for udder washing is used long after the compressor stops running hence insulation of the unit itself is important. Also, rate of use for udder washing is very low (60 to 100 litres per hour) hence effective pipe insulation is very important.

Plant cleaning by acidified boiling water means that the boiler fills up immediately after milking and this happens at a time when water in the HRU is at its lowest temperature. After entering the ABW boiler the preheated water stands up to 10 hours before further heating takes place hence the need for good insulation.

Preheated water requires less heating time in the ABW boiler hence time clocks must be carefully set to minimise the holding time at high temperatures. The volume of water which can be preheated will exceed that which is required except on units of less than about 50 cows. When calculating potential savings by heat recovery care should be taken to do so on the basis of the amount of hot water *actually required* and not on the volume of water a particular HRU is capable of pre-heating.

Economies of scale would be more favourable with pre-cooling rather than heat recovery. For a small additional cost the capacity of a pre-cooler can be doubled, allowing for the herd size to be doubled. Energy savings would also double with the result that the investment would pay for itself much sooner. Similar economies of scale are not possible for the heat recovery system. As the herd size increased, the amount of hot water needed for plant cleaning will not increase proportionally. The volume of udder wash water required would increase proportionally to the increase in herd size but the overall economy of scale would be less than for pre-cooling.

A drop in cooling performance was noted in February 1979 and refrigeration engineers were called to make the necessary repairs. Only after the *third* visit by these engineers was the performance back to normal. Had this drop in performance gone unnoticed as could well have been the case on most commercial farms it would have resulted in an increase in use of over 3000 units of electricity per annum on an average 100 cow herd. There may be a case for having a watt meter installed to record total power for milk cooling to monitor performance rather than have regular service arrangements.

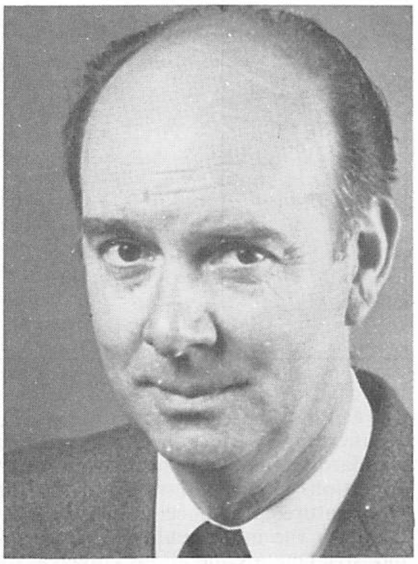
A field survey carried out in England and Wales by ADAS covering eight farms with pre-cooling and seven without showed poorer results than obtained at Craibstone. Certainly colder ambient temperature and colder water temperatures would favour pre-cooling in this area.

Corrosion prevention in agriculture

R J Bishop

Summary

THE rising costs of materials of construction and, even more significantly, of energy are underlining the economic necessity to either prevent or at least alleviate the destruction and degradation of agricultural artifacts, such as machinery, equipment and buildings. The paper outlines the basic philosophy of corrosion prevention in practical terms and describes ways in which the evolved principles have been applied advantageously to corrosion problems which may be broadly described as agricultural. Whilst attention is mainly directed to metallic materials, the durability of ceramics and polymers is also examined. It is suggested that, in parallel with evident trends in automobile engineering, there is likely to be a developing demand for corrosion-resistant agricultural engineering products that give longevity and high availability for service.



The magnitude of the problem

From time to time it has become customary to attempt to assess the real cost to the nation of metallic corrosion; current estimates are in the order of £2 x 10^9 per annum. The general literature on corrosion topics is vast; however, the number of papers describing specialised investigations of corrosion in an agricultural context is surprisingly small. Largely because of our humid climate, the sight of corroding metalwork on farm equipment and buildings is commonplace and is usually regarded as an inescapable feature of agricultural activities. Against this background, the 1977 Conference on Corrosion in Agriculture, which was held at the University of Nottingham under the auspices of the Institution of Agricultural Engineers and the Department of Industry, was timely and can be reasonably regarded as the first serious examination of the subject. The published Proceedings of the Conference[1] clearly set the scene, identify the problems and indicate the ways in which designers and manufacturers have responded to the various challenges. In possible contrast to the specialised accounts contained in these Proceedings, the present paper attempts to present a more general view of the common ground between agricultural engineers and materials/corrosion technologists and to relate the tried philosophies of corrosion prevention to agricultural problems.

Typical indirect costs, arising from the ravages of corrosion, include:

i) preventive and remedial maintenance eg painting of structures,
ii) replacement of components, eg mechanisms which demand close dimensional tolerances,
iii) compensation resulting from liability under the Health and Safety Work Act, eg accidents due to corroded structures.
iv) loss of availability of equipment, eg seizure of bearings during storage.

These items are becoming more and more significant as the complexity of farm machinery and equipment increases and as greater volumes of potentially corrosive solutions are handled. There is, of course, the unique problem that some machinery is only used for a short period each year; sheltered storage space tends to be in short supply and long-term exposure to corrosive conditions is frequently unavoidable.

Although the cost of corrosion is usually considered in terms of lost metallic material, it is the associated loss of the energy consumed in producing this material that is ultimately the most significant and worrying aspect of corrosion. Mild steel may appear to be a rather prosaic material of construction but, overall, its production incurs an appreciable expenditure of energy, eg ore mining, transportation, smelting, refining, working, etc. A recent estimate affirms that the UK loses 1 tonne of steel by rusting every 90 seconds and that production of this mass of steel required 40 x 10^9 joules of energy. This fundamental connection between materials and energy came into uncomfortable prominence on the industrial and economic scene when crude oil prices tripled and quadrupled in 1973/4.

Philosophy of corrosion prevention

Man's achievement in producing metals and alloys is, in one sense, a flouting of the laws of thermodynamics. Metallic materials that have been laboriously produced from ores are usually unstable, and given appropriate conditions, will revert by corrosion to a physical form that is often very similar to that of the original ore. This degradation takes a variety of forms, eg general corrosion, pitting, corrosion-fatigue, stress-corrosion cracking, wear-assisted corrosion, etc., and may proceed rapidly or slowly, with or without warning signs. These forms have already been studied extensively in an industrial context; they are also likely to be found in all their variety in agriculture.

During their training, engineers usually take an introductory course on corrosion theory and meet the electrochemical concepts of electrode potential, Electrochemical Series and Pourbaix diagrams[2]. A general, not necessarily deep, appreciation of the basic principles is usually quite sufficient for the practising engineer. Designs benefit because potential problems are more likely to be recognised at the drawing-board stage.

A typical metallic element, such as iron, tends to discard electrons and enter a contacting solution as positively-charged ions, causing the remaining iron to accumulate a negative (anodic) charge. The Electrochemical Series (table 1) expresses the tendency of different elements to dissolve and indicates the relative polarity of metals coupled in a galvanic corrosion cell (fig 1). Such cells can develop a significant difference in electrical potential, with the rate of dissolution (corrosion) of the anodic surface increasing as the rate of electron flow increases. It follows that means for slowing down, halting or even reversing the electron flow will prevent or alleviate metallic corrosion.

Fortunately for mankind, the initial potential difference between anodic and cathodic elements that is given in the Electrochemical Series decays fairly

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R J Bishop BSc Met(Eng) PhD CEng MIM MIEnergy, Senior Lecturer in Materials, The Polytechnic, Wolverhampton; involved in HND course in Agricultural Engineering, operated jointly by the Harper Adams Agricultural College, Newport, Salop and The Polytechnic.

The paper is based upon a lecture given to the Wrekin Branch of the Institution of Agricultural Engineers, on 8 December 1980.

Table 1 **Coupling of dissimilar metals and alloys (selected examples)**

Electrochemical Series			*Galvanic Series*
Potential V	*Electrode reaction*	↑	
−2.38	$Mg^{2+} + 2e = Mg$	ANODIC (attacked)	Magnesium Alloys
−1.66	$Al^{3+} + 3e = Al$		Aluminium
−0.76	$Zn^{2+} + 2e = Zn$		Zinc
−0.44	$Fe^{2+} + 2e = Fe$		Mild Steel
			Cast Iron
−0.13	$Pb^{2+} + 2e = Pb$	CATHODIC (protected)	Lead
			Brasses
+0.34	$Cu^{2+} + 2e = Cu$		Copper
			Monel
			Type 304 stainless steel
		↓	Graphite

rapidly with time as a result of polarisation effects (fig 2). Furthermore because the Series refers to standardised and very specific laboratory conditions of solution strength and temperature, engineers customarily resort to the more qualitative listing of industrial metals and alloys known as the Galvanic Series (table 1). The identity of the reference solution* greatly influences the positioning of metals within the Series.

Pourbaix diagrams are more directly informative than the two Series mentioned. Their introduction in the 1950's revolutionised corrosion science and had an impact comparable to that of phase diagrams in metallurgy and ceramics technology. Essentially, Pourbaix diagrams define the conditions (temperature, potential, solution pH) under which corrosion of a given metal "does, may not or does not" occur.

The principal ways of preventing or inhibiting corrosion will now be considered, together with examples drawn from agricultural practice, under the headings:—

i) Choice of material
ii) Control of the corrosive environment
iii) Provision of a corrosion barrier
iv) Designing against corrosion.

Choice of material

Wood is the first contender for general structural applications, being fibrous and tough, strong and light. Although useful for storage bins for cereals and grass seed[4], trailers, box-type manure-spreaders, etc, its limited long-term resistance to decay and attack by chemically active solutions naturally tends to restrict its application. With regard to man-made materials, choice can next be made from a wide range of metals and alloys, ceramics and polymers ('plastics').

When considerations of strength, stiffness and wear-resistance are paramount, metallic materials are likely to be the engineering choice. If mildly corrosive conditions are anticipated, there might be an attendant hope that the material will form its own 'protective' scale during service. Unfortunately, with most plain or low-alloy materials, this does not happen. The scientific reason is that oxide and/or scale layers on metallic surfaces are usually flawed and defective so that movement of gases, ions and electrons is unrestricted.

The so-called 'stainless' steels are an outstanding example of the way in whcih corrosion resistance can be promoted by alloying and they find wide use in the dairy and food industries[5], where cleanliness and sterility are essential. Austenitic 18 chromium-8 nickel stainless steel contains sufficient chromium to form a thin protective (passive) film of chromium oxide immediately it is exposed to air. However, such steel is not always "stainless'; chlorine ions in solution are capable of breaking down this film and causing pitting attack. In situ cleaning of stainless steels therefore demands careful control of the strength of sterilising/cleaning solutions. For instance it is essential to control the pH of chlorine-containing sodium hypochlorite sterilising solutions within the range 8 — 9 and to rinse thoroughly with clean water afterwards. Pitting attack, which is generally regarded as being more serious and dangerous than general surface wastage, may occur unexpectedly in processing plant. In one case, an austenitic stainless steel (Type 304) heat exchanger in a beet sugar mill developed serious pitting on the sugary water side of the heat transfer plates. Chlorides ions appeared to be responsible and a change to the nickel-bearing Alloy 825 was eventually recommended. In dairy processing, austenitic stainless steels such as Type 304 are used in the new heat recovery systems[6] which use the energy content of warm milk to heat stored water[7]. Stainless steel has also been used for machine components that must retain dimensional accuracy eg vanes on fertiliser spreaders. The high cost of stainless steels tends to restrict their use in structural applications; nevertheless, they can be particularly useful for high-risk corrosion areas eg ferritic 17% chromium steel has been used for floor-level partitioning in pig-breeding buildings.

Stabilised austenitic steels can be conveniently fabricated by welding but it is still often forgotten that the choice of weld filler is of crucial importance. Much

Sea water, being corrosive, is a common choice; Hardly agricultural but it is of interest to designers of cages for the new industry of sea fish farming. One cm mesh cages are made from 90 copper 10 nickel alloy which resists corrosion and remains free from marine growth[3]

Fig 1 Galvanic corrosion

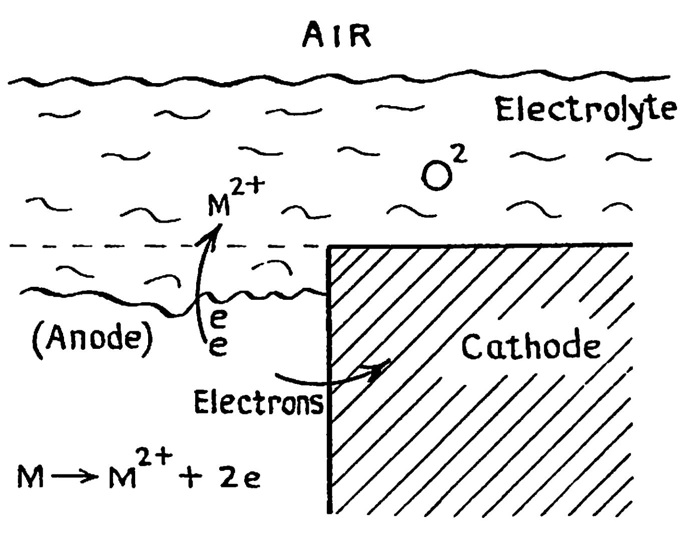
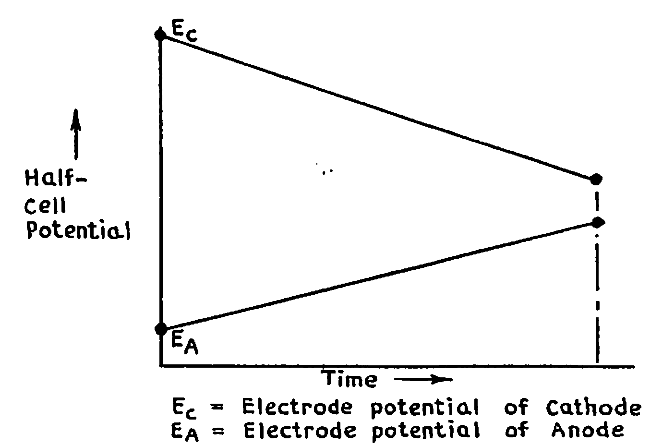


Fig 2 Decrease in cell potential with time



to the chagrin of insurance companies, mild steel filler rods are still sometimes used in joining stainless steel, creating a dangerous galvanic couple in which attack is concentrated on the relatively small anodic area of the weld. Stainless steels resist oxidation ('dry' corrosion) at temperatures above 600°C and attack by acidic condensates, and, in comparatively recent times, have been used to replace the ubiquitous mild steel of exhaust silencers for cars. Some years ago, an American long-distance haulage firm adopted heat-resistance nickel-base alloys for silencers (mufflers) and reported substantial cost savings. This type of maintenance philosophy is obviously always worth considering in agriculture.

Before leaving metallic materials, it is appropriate to mention briefly the subject of alloy development. Sometimes, when a new form of corrosion becomes apparent, the suggestion is made by engineers that it might be worthwhile to develop a new custom-made alloy. Closer study usually reveals that research and development costs are extremely high and that final sales will be unlikely to justify the effort. On the other hand, study and modification of existing commercial alloys can produce dividends. Thus recent research by the British Non-Ferrous Metals Research establishment showed that closer control of the copper/zinc ratio in 60/40 casting brass can virtually eliminate its susceptibility to dezincification in aqueous solution[8].

So far as non-metallic materials are concerned, the new class of engineering ceramics is worth considering for agricultural applications where resistance to corrosion and/or wear are essential requirements. In contrast to the traditional kiln-fired ceramic materials, with their fairly porous texture and brittle structure, materials such as silicon nitride and glass-ceramics are dense, strong and can be produced in accurately-dimensioned and complex shapes. Like all ceramics, they are chemically stable and therefore generally resistant to corrosion.

A more commonplace ceramic material, concrete, finds wide-spread use in agriculture, and significantly, an account of its structure and properties aroused much interest at the Nottingham Conference[9]. Concrete is regarded by the materials technologist as a two-phase composite made up of aggregate particles in a matrix of hardened cement (usually Portland). The cementitious phase, being rich in calcium oxide and basic in character, is attacked by acidic solutions, such as marshy waters containing dissolved carbon dioxide. To a lesser extent, sugar solutions, animal fats, vegetable oils and sulphate solutions derived from the soil can also cause degradation of concrete. The surface of concrete floors can be slowly destroyed by cycles of capillary attack and wear (fig 3). Calcium chloride is sometimes added to the concrete mix in order to accelerate the curing (setting) reactions within the cement paste but will attack steel reinforcement bars and lead to bursting of the concrete by developing rust. It is preferable to accelerate the reactions by keeping the setting mixture warm. Whilst concrete can hardly be regarded as completely resistant to chemical attack by solutions encountered on farms, it is nevertheless advisable to try and follow the three C's of good concreting practice, namely, correct proportioning, compaction to eliminate voids and careful curing.

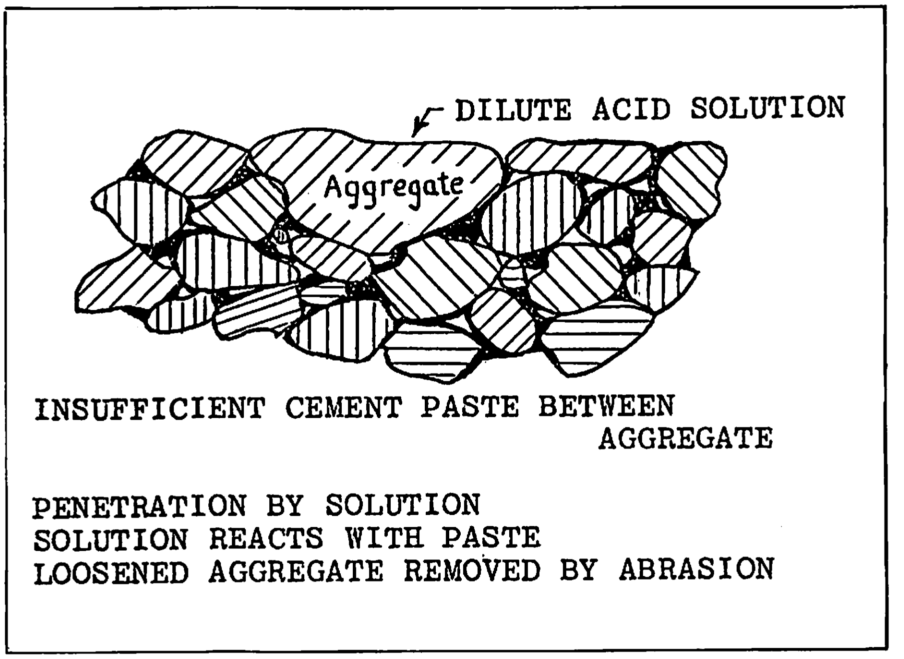


Fig 3 Surface degradation of concrete[9]

Polymers are generally regarded as being resistant to degradation in service in temperate and tropical climates and, depending upon structure, have properties that range from tough and soft ("plastic") to brittle and hard. They are commonly available in film, sheet and tubular forms for agriculture, finding use in greenhouses (polyethylene), baler twine, long hinges and water reservoirs (polypropylene), windbreaks (glass 'reinforced' polymer and polyvinyl chloride), field drainage pipes (high-density polyethylene and polyvinyl chloride) and grain feed mechanisms (nylon and ABS)[10].

Degradation of some polymers can be caused by the short wavelength ultra-violet radiations in strong sunlight because the quanta, or photons, are sufficiently energetic to sever the covalent bonds between atoms in the long chain molecules of the polymeric structure. Structural changes lead to property changes and the polymer is said to age. Being organic substances, polymer can also be attacked by soil acids and by the secretions of micro-organisms such as bacteria and fungi. Scanning electron microscopy has shown that compost can cause pitting of previously smooth polyvinyl chloride surfaces[11].

In cases where the specific strength and/or specific modulus of elasticity of polymers are unacceptably low, the ncorporation of 'reinforcing' filaments of glass or carbon can be considered. Such composites (grp and cfrp) have a continuous polymeric matrix that largely determines their resistance to chemical degradation.

Control of the corrosive environment

'Wet' corrosion depends upon the presence of a solution or electrolyte, usually aqueous and possibly only present in minute amounts. It is therefore sensible to prevent solutions from remaining in long-term contact with corrodible materials. Modern agriculture employs or produces many extremely corrosive solutions, such as fertilisers, and washing down of vulnerable components is generally recommended. Alternatively, it is sometimes possible to modify the solution phase so that its corrosiveness is reduced. This approach was adopted by Berry[12] of BP Chemicals in tackling the corrosion problem associated with the propionic acid solution which is used to prevent mould and bacteria formation in grain during storage. A proprietary additive (Add-H) dramatically decreases the tendency of the sprayed-on acid solution to attack the steel of the storage bin (table 2).

Inevitably, there are situations where elimination or modification of the solution phase is either impossible or impracticable and a different approach is necessary. In New Zealand, light aircraft are used extensively for spraying pasture lands with superphosphate fertiliser dusts. Justifiable concern was expressed about the conjoint action of the dusts and cyclic stressing upon aluminium alloy components of the aircraft. Dynamic tests showed the damp dusts shortened the fatigue life of the solution-treated and naturally-aged aluminium alloy in question. Dry dusts were found to be comparatively innocuous. However, as complete elimination of moisture under spraying conditions is impossible to achieve, it was finally recommended that the aircraft should be inspected meticulously and regularly for signs of incipient corrosion-fatigue[13].

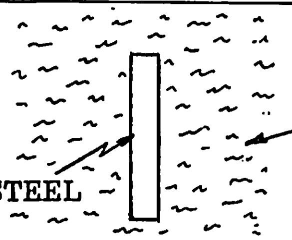
In addition to their ability to attack

polymers directly, micro-organisms are capable of promoting metallic corrosion by converting soil chemicals into highly corrosive species eg sulphates are reduced to free sulphur by bacterium Desulfovibrio desulfuricans. Cast iron or steel pipes buried in water-logged clay or in soil polluted by organic matter can suffer from extreme rapid attack; ¼ inch thick pipe walls have been perforated in a period of 4 years. When cast iron or steel pipes are chosen for under-ground service and there is a possibility of microbial corrosion, it is advisable to:

i) check upon the 'aggressiveness' of the soil
ii) provide good drainage
iii) consider the use of an alkaline back-fill to the trench
iv) consider the need for a small applied voltage (cathodic protection) to oppose any undesired electron flow[14].

The surrounding atmosphere can, of course, change the chemical composition of the solution phase and make it more corrosive. In the UK, farms are usually within 100-200 miles of large industrialised conurbations and it is possible for traces of sulphur dioxide to enter rural waters from the atmosphere and increase their corrosiveness. (The scale of this particular problem can be gauged from the recent claims that sulphur dioxide emitted by coal-fired power stations in the UK is contributing to pollution by 'acid rain' in Sweden). Similarly, airborn chlorides will increase corrosion risks in coastal regions. More seriously, under confined or poorly ventilated conditions, local atmospheres may be particularly corrosive e.g. internal roof structures of buildings housing livestock. Ammoniacal vapours are plentiful in agriculture; yet only trace amounts of ammonia are needed to cause sudden cracking of cold-formed brass that is not completely free from residual stresses. This stress-corrosion cracking[15] can usually be prevented by a stress-relieving heat treatment after cold-working. Unfortunately, it is possible for either assembly or service to induce dangerous stresses into annealed material. Washing down large stainless steel tanks with brackish water has been known to cause catastrophic cracking.

Table 2 Inhibition of attack by propionic solution[12]



	CORROSION RATE mm/YEAR
PROPIONIC ACID SOLUTION	0.41
ADD-H SOLUTION	0.12

Table 3 Typical coatings, classified according to method of application

BY WETTING	
i) Hot-dip	Zinc (galvanising) Tin (plating) Lead (sheathing)
ii) Cold-dip or brush painting	Paints and lacquers Plastics and rubbers Vitreous enamels
BY SURFACE CONVERSION	
	Chemical oxidation Phosphate Chromate Anodising (aluminium, magnesium)
BY DIFFUSION	
i) Pack-cementation	Aluminium (Aluminising, Calorising) Chromium (Chromising) Zinc (Sherardising)
ii) Hot cladding	
BY SPRAYING	
	Flame Detonation Arc plasma
BY ELECTRODEPOSITION	
	Plating Electrophoresis (paints)

Provision of a corrosion barrier

The essential purpose of coatings, whether metallic, polymeric or glassy, is to introduce a physical barrier between the solution and the metal/alloy that is to be protected. Ideally, the coating should adhere strongly to the basis metal and be impermeable and unreactive. Table 3 classifies coatings according to method of application and gives some idea of the wide variety of coatings that is available to engineers[16]. Discussion will be restricted to some types of surface and intermediate coatings which are encountered in agricultural practice, namely zinc, paint, phosphates, chromates and vitreous enamels.

Generally speaking, the protective layer of zinc applied by the galvanising process has an impressive ability to protect steel from corrosion. Zinc affords sacrificial protection, being anodic relative to the basis steel, and is able to tolerate a limited amount of mechanical damage. Probably more important, solid corrosion products plug any small breaks in the continuity of the zinc layer and retard corrosion. Modern specifications, which emphasise thickness minima for the zinc rather than previous weight criteria, should be capable of giving protection for some 30 years in a rural environment. Very 'soft' water will tend to attack galvanised coatings and adjacent cement or mortar can generate harmful alkaline conditions. However, the limitations are well understood and practical guidance is readily available on galvanised structures[17], e.g. rain-water tanks[18]. Significantly, galvanised steel is finding increasing use in automobile construction as a means for preventing body corrosion. Naturally, the technology of galvanising has been stimulated by these marketing developments. In the USA, weldable and paintable steel sheet, galvanised on either one side or both sides, is being produced by Armco, together with a new magnesium-bearing grade of zinc coating which has improved corrosion resistance[19].

The ability of a paint barrier to prevent corrosion of the basis steel and withstand damage depends to a great extent upon the quality of steel pre-treatment and a careful balancing of the thickness of its component layers, eg primer, sealer, colour. Pre-treatment cleansing with deionised water is recommended for eliminating soluble salts that might eventually lead to corrosion and blistering of the paint layer. Phosphate conversion coatings develop a thin film of manganese, zinc and/or iron phosphates on clean steel sheet and provide an excellent basis for paint and inhibit corrosion beneath the paint. By itself, a phosphate coating has little intrinsic corrosion resistance. In addition to established proprietary processes, such as parkerising, bonderising and granodising, new variants continue to appear. Thus, in the Vaq-Fos process, the blasting action of alumina grit and a phosphate solution combines cleaning and coating operations. British Rail has developed a 'T-wash' for galvanised steel and structural steelwork which can be brushed on, in contrast to the usual hot-dip tank or spray methods, and painted after two hours. Energy-saving is possible with newly-developed zinc phosphate pre-treatment baths that operate at only 30°C.

Chromate treatments, like phosphate treatments, convert the surface by chemical reactions. They improve the corrosion resistance of anodised aluminium and magnesium alloys, bare metal, phosphated metal and galvanised surfaces. For instance, a chromate treatment will inhibit 'white rust' formation on galvanised sheet in humid atmospheres.

Unlike conventional metals and alloys, which are crystalline in structure, vitreous enamel coatings consist of oxides in a glassy non-crystalline state and are unreactive in most environments. Since World War II, when American technologists experimented with thousands of novel formulations, enamels have found increasing use in engineering applications at ambient and high temperatures. Water heater elements have traditionally been made from nickel-based alloys, such as Monel; however, it is now anticipated that the cheaper designs using enamelled plain carbon steel will shortly appear in the UK. Enamelled exhaust manifolds, first introduced on quality cars, are to be found on tractors. On a grander scale, vitreous enamelled steel plates are used in the construction of large tower silos for the storage of grass and grain[20]. The juices can be very corrosive; for instance, the juices associated with maize are highly acidic and at fermentation temperatures in the order of 30°C will corrode steel. Even zinc is attacked and, of necessity, the securing galvanised bolts are coated with a plastic compound. Corrosive slurry is stored in tanks of similar construction and enamel has presented an effective barrier to the action of urea and ammonia. In fact, sedimentation of solids and attack of surrounding concrete floors by slurry probably present much more serious problems than wastage of the tank walls by corrosion.

Designing against a corrosion

There are usually areas of corrosion risk on any machine or in any farm building and it is instructive to inspect them after a period of service. (One might expect that, as with automobiles, agricultural machinery occasionally starts corroding on the stockist's premises before it reaches the customer). The merits of simple drainage holes are sometimes overlooked and on typical farming equipment one can often find side frame members which collect several inches of water. Sloping surfaces which shed water and the provision of clear access for good ventilation or easy maintenance give long-term benefits, e.g. undersides of steel storage tanks.[2] Water-absorbent materials, such as wood, hard-board and plaster, should be kept away from corrodible materials. In buildings, the lower portions of vertical steel supports are often vulnerable and a surrounding sheath of concrete with sloping top surfaces is helpful. This problem occurs in animal houses where condensed moisture drains downwards and is trapped at floor level. In the presence of aggressive manure, as mentioned earlier, floor-level partitioning in stainless steel can be worthwhile.

Although galvanic action between dissimilar metals is well-documented, injudicious combinations still appear far too frequently in designs. If a potentially risky combination is unavoidable, the designer may consider either breaking the electron flow by an insulation layer or decreasing the cathode area/anode area ratio in order to reduce the density of the corrosion current at the anode.

Meticulous surface cleansing and preparation are essential before paint is applied and exact procedures need to be specified in designs. With mass production methods these aims are understandably difficult to achieve and one occasionally sees thread-like patterns of filiform corrosion on painted sheet steel. As indicated earlier, oxide scale is not protective; indeed, if patches of millscale are left on rolled steel girders, the underlying steel is liable to pit. In this type of differential aeration cell a potential difference develops between regions of different oxygen concentration. For similar reasons, corrosion occurs under crevice conditions in the water-cooling systems of engines and simple deficiencies such as incorrectly located core plugs and carelessly fitted radiator hoses, can lead to highly localised corrosion.

Good Husbandry

With the increasing cost of materials, it seems inevitable that tolerant attitudes towards the corrosion of machinery and buildings will gradually disappear, and that new machinery designs will be judged increasingly in terms of their likely longevity and long-term availability. The underlying philosophy of prevention is essentially straightforward and readily appreciated; nevertheless, recommendations that attempts at prevention are worthwhile and should be seriously considered do not necessarily find acceptance.

The burden of deciding how much corrosion resistance needs to be built into agricultural machinery and buildings rests with the design engineer. This task usually involves compromise and is difficult, particularly as the product may need to satisfy foreign as well as home requirements. It is suggested that the trends which have become evident in the philosophy of the automobile industry will eventually be mirrored in agricultural engineering. Thus, with cars, longevity and reliability are becoming prime selling points, displacing more fashionable whims, with some leading firms now offering nominal guarantees from corrosion for periods of at least six years. In the USA, an Anti-Corrosion Code has been formulated to assist automobile manufacturers and one naturally wonders about the possible extension of such praiseworthy ideas to tractors and farming machinery in general.

In the meantime, whilst the user of agricultural equipment continues to be confronted with a variety of corrosion problems, the best advice seems to be summed up in the old advice that 'cleanliness is, indeed, next to godliness'.

Washing down equipment after use is frequently beneficial just as it is advisable to remove mud poultices from the undersides of road vehicles. (Such accretions are slow to dry out, harbour deicing salts from roads and starve the underlying metal of oxygen). Good ventilation during storage is beneficial whereas storage of damp metallic equipment in a warm, sealed building is likely to be detrimental. Temporary protection can be given to vital working surfaces, such as ploughshares after each day's work, by a variety of protective oils and greases.[21] Combustion engines form acidic condensates and can corrode internally during protracted storage; special engine lubricants are available to give appropriate protection. As in many other fields of human activity, small deficiencies can lead to disproportionately large difficulties; essentially, the science of corrosion technology is a recognition of this possibility.

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Institution of Agricultural Engineers

Spring National Conference

(in association with West Midlands Branch)
on Tuesday, 16 March 1982
at The National Agricultural Centre, Stoneleigh.

Engineering for Meat Production

The objectives are to:
(a) review the full range of factors influencing the development of meat production technique
(b) review the more recent and significant engineering developments in this field
(c) identify the potential contribution of Agricultural Engineers to future developments.

Conference Chairman: Dr K Baker, Director of Operations, Meat and Livestock Commission.

Speakers:

Professor P Wilson, Chief Agriculturalist, British Oil and Cake Mills/Silcock Ltd, will discuss factors influencing meat production in the future.

P Spencer, Bernard Matthews Ltd, will discuss housing and feeding systems for poultry.

A Smith, Agricultural Development and Advisory Service, National Pig Environment Specialist, will discuss the housing and feeding of pigs.

Dr M Kay, Head of Animal Husbandry Division, School of Agriculture, Aberdeen, will discuss meat production from ruminants — future demands on the Engineer.

S W R Cox, Deputy Director, National Institute of Agricultural Engineering, will discuss monitoring animal performance.

Annual Conference

on Tuesday, 11 May 1982
at The National Agricultural Centre, Stoneleigh.

Engineering developments for the Drying, Storage and Handling of Cereals

Conference Chairman: Mr H Watt, Farmer, Broadcaster and Writer.

Topics to be discussed will be:

Developments in continuous flow grain drying,
by **Dr M E Nellist,** Head of Crop Drying and Ventilation Department at the National Institute of Agricultural Engineering.

Mobile grain driers,
by **A D Wilcher,** Service Manager, OPICO (UK) Limited.

Developments to assist with drying and storage of grain in silos and on-floor systems.
by **W Bindloss,** Grain Storage Manager, P A Turney Limited.

Developments regarding co-operative cereal storage and drying,
by **P Webb,** Director of T H White Installations Limited.

Storage and conditioning of malting barley,
by **O Griffin,** Tore Mill Limited.

The application of reliability engineering to farm machinery

R Wingate-Hill

Summary

THE limited amount of published information on farm machinery reliability is reviewed. Problems of achieving satisfactory reliability in agricultural machines are discussed plus the penalties which manufacturers may face if they fail to achieve this reliability, especially when failures cause injury to the operator. Improved reliability obviously requires a major effort by manufacturers, but it is pointed out that practically all other sectors of the farm machinery industry, including farmers and researchers are able to provide valuable assistance and the ways in which they can do this are discussed.

Introduction

AS more and more capital, in the form of machinery, replaces labour on farms the reliability of this equipment assumes greater importance, especially in one-man enterprises with single sets of equipment. There is an increasing interest by all sections of the agricultural machinery industry in Australia and in the USA on machine reliability, no doubt due in large part to the great deal of publicity given to failures of some large tractors used in broadacre crop production (for example Holligan, 1979 and Buckingham, 1979).

The range of literature dealing with farm machinery reliability is very limited, in fact surprisingly so compared with the vast amounts relating to reliability in other fields of engineering. In 1962 Gruben and Lilyedahl developed a model for estimating the reliability of maize harvesters and about the same time Archer (1963) described the steps involved in applying a reliability improvement programme to the manufacture of farm machinery.

Richardson, *et al* (1967), carried out a survey of farm machinery durability and later Von Bargen (1970) formulated a model to predict the effect on performance of a maize planting system of delays due to management problems, adverse field conditions and machinery reliability. Hunt (1971) reported the results of a survey concerned with the incidence of breakdowns, lost time and repair costs experienced by maize and soybean farmers. In 1977 Kumar *et al* and Hollenback and Schmitt both published papers on reliability engineering concepts applied to combine harvesters and Wood (1977), discussed improvements in machinery reliability at the ASAE Grain and Forage Harvesting Conference. The latest edition of the ASAE Agricultural Engineers' Handbook (Anon[1], 1979), contains, for the first time, some information on farm machinery reliability. A seeder reliability survey has recently been completed in Western Australia (Anon[2], 1979), and a tractor reliability survey is well under way in Queensland and Northern New South Wales (Tullberg, 1979).

R Wingate-Hill BSc MSc(MEng) MSc(AgrEng) MA CEng MIMechE FIAgrE MIEAust, formerly Officer-in-Charge, Agricultural Engineering Centre, New South Wales, Department of Agriculture

Reliability engineering techniques and terminology are well developed, mostly in the electronics, aerospace and nuclear engineering industries. They are undoubtedly being used in the research and development and design departments of some of the large multi-national agricultural machinery manufacturers but there is considerable scope and benefit to be gained from their wider application. It appears to the author that the great need is for more information of a detailed nature on farm machinery operating times and conditions, and on the exact circumstances under which failures occur and their frequency distribution. This would assist the designer and manufacturer in producing more reliable equipment. The paper, therefore will deal mainly with specific data needs, their collection and analysis, use and value to the manufacturer, distributor, purchaser and operator of farm machinery. But first some definitions and a little theory will be dealt with.

Definitions and theory

Reliability concepts are discussed in Anon (1972). Only a few of the more common terms are mentioned here. A generally acceptable definition of reliability is: "The probability that the equipment will complete a specific task under specified conditions for a stated period of time (or distance, or number of revolutions, etc)".

Failure is the termination of the ability of an item to perform its required function. Whereas, the failure rate of a population of items for a period of time from t^1 to t^2 is the number of items which fail per unit time in that period expressed as a fraction of the number of non-failed items at time t^1 (Blanks, 1979).

For convenience, the normal measure of failure frequency used is the inverse of the failure rate which is called the Mean Time Between Failures (MTBF). This may also be expressed in terms of distance, cycles or other appropriate variables. For a repaired item the observed MTBF is, for a stated period in the life of the item, the mean value of the length of time between consecutive failures computed as the ratio of the cumulative observed time to the number of failures, under stated conditions (Anon, 1977).

It has been found for a wide range of mechanical and electrical equipment that the failure rate of the population tends to vary throughout the equipment's life in the way shown in figure 1 — the so called 'bath-tub' curve.

In the 'Infant Mortality' period failure rate is often initially high due to weak or sub-standard components, but usually decreases rapidly and stabilizes at a relatively constant level for the whole population. This is the "Constant Failure Rate", or "Useful Life" period when failures usually occur randomly. Ultimately, however, as the equipment comes to the end of its useful life it enters the "Wear-out" region in which the failure rate increases. For well designed equipment the major proportion of its life lies in the "Constant Failure Rate" period in which reliability (R), (that is, probability of survival), can be expressed in the exponential equation.

$$R = e^{-\lambda T} \qquad (1)$$

where, e = base of Naperian logarithms

λ = failure rate (inverse of the MTBF)

T = total time of test or observation

Commissioning periods, running in, etc are practical methods of eliminating

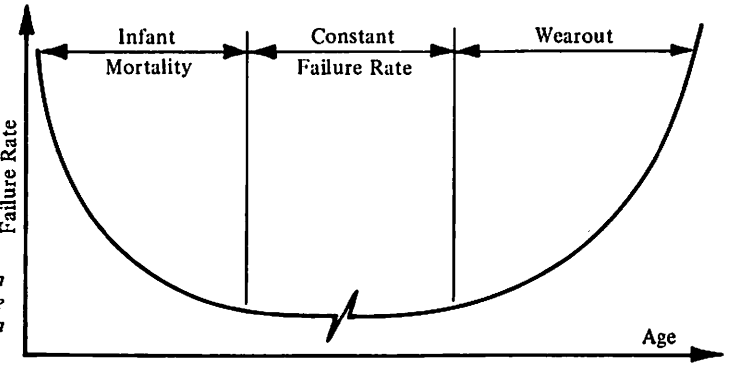


Fig 1 Variation in failure rate during a machine's life

infant mortality failures before 'field use'. The occurrence of wear out failures can generally be prevented by scrapping and replacing items before the onset of wear-out life, provided this has been determined during the products development phase. However in the "Constant Failure Rate" region the replacement of non worn-out item by a new one will not improve reliability because failures in this region are random in nature and cannot be predicted.

In the absence of redundancy, the reliability of a combination of components or machines is the product of the individual reliabilities. The reliability of individual components which are essential for the functioning of complex machines must therefore be very high if satisfactory operational reliability is to be achieved. Take a hypothetical tractor as an example. If the engine, transmission, tyres and steering system have reliabilities of 0.85, 0.95, 0.98 and 0.95, respectively for operation in specified conditions, then the reliability of the tractor as a whole is only 0.75. In other words there is a one in four chance that it will breakdown within the specified period of operation. It is of course very costly to achieve extremely high levels of reliability in individual components and there must be a trade-off between total machine reliability and cost to the purchaser/operator.

Benefits of increased reliability

For the farmer, more reliable machinery essentially leads to decreased costs (unless the increase in cost of a more reliable machine outweighs these savings) and less risk of income losses as well as generally making his management function easier. More specifically, timeliness of operations is important in obtaining high yields and machinery breakdowns especially at busy periods such as sowing or harvest, can lead to large losses of revenue quite apart from the cost of repairing the equipment. If estimates could be made of when equipment was likely to fail, this would assist in planning machinery purchases and spare parts inventories and reduce costs.

For the manufacturer, careful attention to quality and reliability (Q & R) during task definition, design, prototype testing, production, and despatch can bring many benefits especially if it is combined with a good network of well informed dealers and service agents who are willing and able to competently instruct the owner/user of the equipment in the correct, safe operating techniques and provide a fast, efficient spare parts service if failures do occur. The benefits may be listed as:

(i) Avoidance of non-viable development programmes and premature or aborted production runs. J T Duane and others (Blanks, 1979), have found that during machine development as long as there is an active reliability improvement programme in operation, ie through use of failure diagnosis, information feedback and corrective action, then the MTBF will increase at a predictable rate.

Duanes' model can, therefore, be used for early forecasting of the length of development programmes required to achieve a desired MTBF.

(ii) Minimisation of losses caused by having to scrap or re-work work in progress or completed products which do not meet quality and reliability standards.

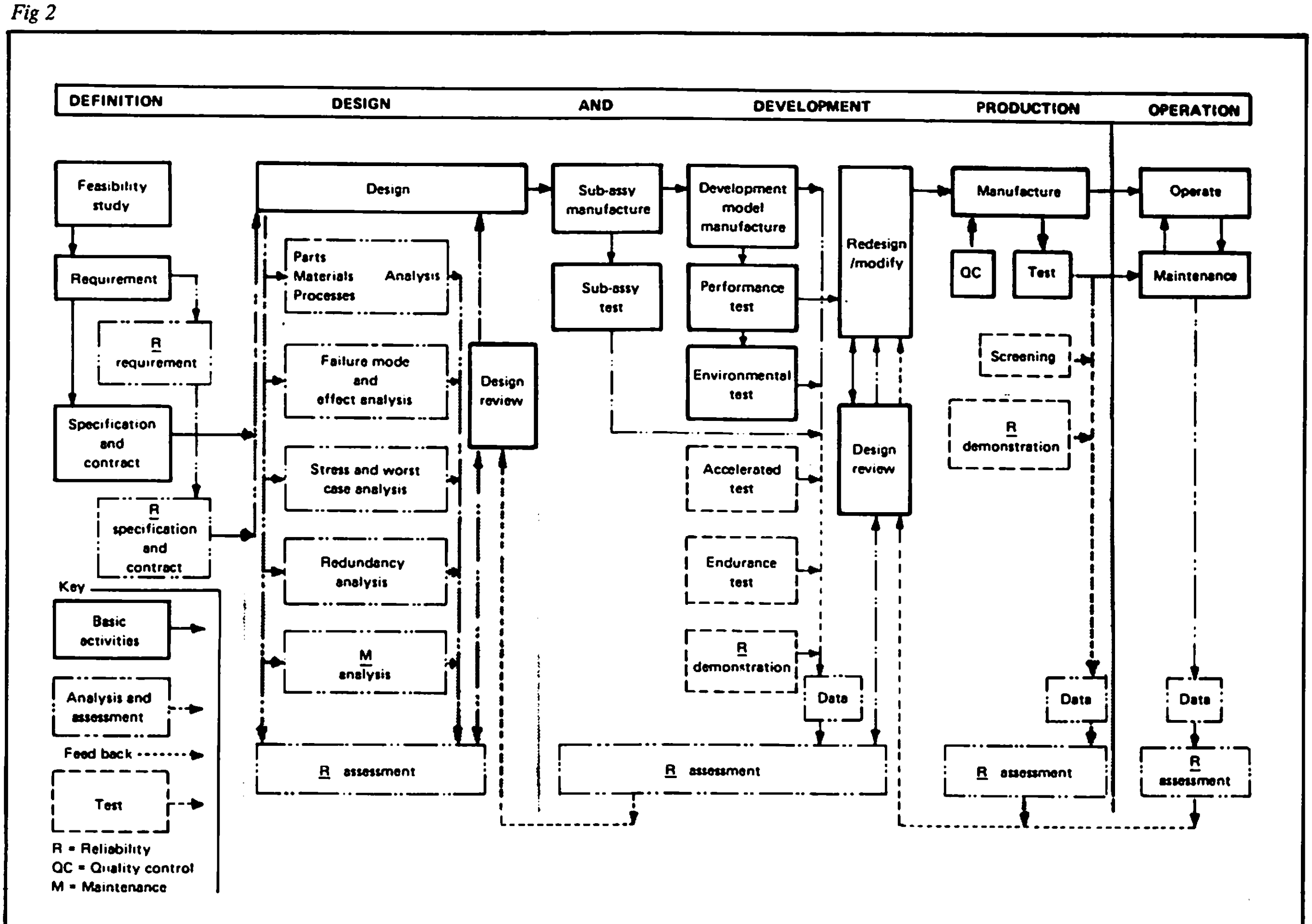
(iii) Avoidance of delayed payments and large numbers of warranty claims by customers plus loss of future customers.

(iv) Eliminating or minimisation of product liability claims which can involve legal costs, awarded damaged in the case of injury or disease caused by a machine failure, plus product recall and rectification costs. This aspect of Q & R has recently assumed great prominence and warrants special mention.

Product liability legislation

Relevant USA and European legislation has adopted the concept of "strict" liability, ie liability is not dependent on negligence having to be proved. Liability for death or injury caused by a product 'defect' may extend from the producer or importer to his designers, distributors, component suppliers and may even, it seems, involve members of committees who write relevant standards (Blanks, 1977). In the European legislation, "The defect in the product may be due to a design fault, workmanship, test

Fig 2



omissions, material substitutions, inspection errors, inadequate markings or warnings, inadequate or improper instructions, inadequate packing or packaging, improper maintenance or installation, misleading advertising or improper marketing". Probably more disturbing, however, is the acceptance of the principle that " ... whether or not a product is defective is related to its foreseeable use and the state of the art at the time of loss ..." (Jacobs and Mihalasky, 1977). Also a recent Californian Supreme Court opinion quoted by von Huelsen (1978) states that, inter alia, "... in design defect cases, a court may properly instruct a jury that a product is defective in design if ... the plantiff proves that the products' design proximately caused injury and the defendant fails to prove, in the light of relevant factors, that on balance the benefits of the challenged design outweigh the risk of danger inherent in such design". In future the farm machinery manufacturers will face considerable problems in designing for increased reliability and safety. Unless they can solve these problems, they may face high risks of prosecution. For example, in a recent judgment against a major USA farm machinery manufacturer $m15.65 US was awarded to a farmer who sustained severe burns following a tractor fire allegedly caused by a defective fuel tank cap (Anon[3], 1979). It seems likely that legislation similar to that mentioned above may soon be introduced into Australia. Indeed the NSW Government has already amended its consumer protection legislation so that farmers are included as consumers and the former upper limit of $15,000 on purchases has been removed. This has opened the way for farmers to receive government assistance in legitimate complaints against suppliers and/or manufacturers of unreliable or faulty farm machinery and equipment (NSW Parliamentary Debates, 1980).

Methods of achieving reliability

The institution and operation of a product reliability programme is a complex and skilled task which will only be mentioned briefly here. Figure 2 (taken from Anon, 1977) applies to electronic equipment, but the principles are similar for mechanical equipment, and the figure serves to show that the achievement of reliability is a team effort starting with the designer and involving all phases of production, marketing and, very important, feedback from the final user.

The first task, definition, is a difficult problem with farm machinery. The stages are to define exactly what the machine is expected to do in quantitative terms, for how long, under what environmental conditions and at what cost as reflected in final selling price (in other words to draw up a detailed specification). At this point reliability requirements start to emerge, for example, a calculated total quantity of material must be delivered by a metering mechanism within prescribed tolerance limits without failing due to abrasive wear or fatigue, before this total has been reached. The advantage of defining these "design guidelines" as closely as possible is that the designers task is made easier, the test engineer knows what he is testing for and finally management can assess more easily when the prototype stage should end and production begin.

Following acceptance of a feasibility study on the detailed specification in which the likely reliability of components, assemblies and the whole machine are assessed, detailed design can proceed. It is worth mentioning here a well known "rule of thumb" which is seldom referred to in text books, namely, the advantages of simplicity. Simplicity of design generally increases reliability and reduces cost. Unfortunately it is a nebulous parameter which cannot be measured but its converse, complexity has been quantified (Pugh, 1978) as:

$$\text{Complexity} = (Pp \times Pt \times Pi)/f$$

where, Pp = number of parts
Pt = number of different types of parts
Pi = number of interconnections and interfaces
f = number of functions the product is expected to perform

Simplicity is associated with a low complexity factor; the lower the number, the greater the product reliability, the lower its cost and the higher its quality.

During design, failure mode and effect analysis may be used. This is a qualitative procedure which involves a systematic search for the likely failure modes of the systems' components and an analysis of their effects on the operation of other components and on the whole system performance. If system reliability is not acceptable, some redundancy may be required, (though this will usually increase costs) and redundancy analysis will have to be carried out to determine by how much reliability will be improved.

Development will generally proceed parallel with detailed design. In relation to reliability, "development" implies the following types of activity: verifying the feasibility of proposed manufacturing processes, finding weaknesses in completed component designs or assembly prototypes and indicating where and how changes should be made to increase reliability. The next stage in development is reliability evaluation of complete prototype machine or systems which may involve testing to determine failure rate and MTBF, determination of margins of safety by stressing to failure etc. This activity should discover causes of unreliability or points of weakness so that corrective action can be taken prior to production.

Pilot production usually follows successful development in order to permit 'debugging' of the design and proving the suitability of the manufacturing process prior to full production. During full production a Q & R programme should be maintained to ensure that previously agreed reliability standards are being met (for methods and techniques see Anon, 1972 and 1975).

Finally the completed machines are sold and used, and this is the 'acid' test for the reliability programme. Nearly always there will be some failures in field operation and it is vital that the manufacturer receives feed-back information if such reliability problems are to be rectified.

Collection of information for reliability improvement

Collection of agricultural machinery reliability data does not seem to have received much attention. It is an area where there is a need for co-operation between plant and soil scientists, machinery manufacturers, their agents and farmers plus agricultural engineering units in universities, agricultural colleges, and departments of agriculture as well as machinery testing stations or institutes.

The benefits of such co-operation could be:

(i) If plant and soil scientists work along with engineers the basic functions machines are required to perform and, just as important from a reliability point of view, the tolerance limits within which operation is considered to be satisfactory can be more closely determined. To take an example, the author and his colleagues have recently been concerned with performance testing of combine drills, one aspect being along-the-row distribution of wheat seed. An extensive literature search failed to reveal any quantitative data on interseed spacing distributions required for optimum yield or even limits outside which yield was adversely affected. In other words the combine designer has only vague design or reliability data for the metering mechanism and his company must resort to long and laborious field tests on prototypes to assess each new design.

(ii) There is also a dearth of what may be called "engineering" as opposed to "agronomic" data available to help the designer achieve improved reliability. Ideally if the designer knew the load spectrum which, for example, a given tractor transmission had to withstand for a specified total number of cycles before failure he could design more accurately, laboratory test the prototype relatively quickly and greatly speed up the development process compared with the present methods. Agricultural engineering departments in universities and research institutes could make a significant contribution in this area and an excellent example is the work on power-take-off loads by Crolla and Chestney, (1979).

(iii) Farm machinery surveys are another valuable method of obtaining data for improved reliability. Manufacturers should, of course, survey the reliability of their equipment by asking their agents to collect relevant data on warranty claims, analyse and use it as a guide in making design improvements. They can be greatly assisted, however, by agricultural engineering sections in universities, colleges, Department of Agriculture and agricultural engineering institutes, and of course, by farmers in providing accurate detailed information on machinery failures. Thus many of these institutions have the resources (research students, agricultural mechanisation officers) to carry out surveys of machinery reliability. Conditions and periods of use of various types and sizes of equipment, for example, how many hours per year is a medium powered four wheel drive tractor used, what proportion of this time is spent on heavy draught primary cultivation, light draught secondary cultivation and transport? This data helps to formulate the initial design specifications, and incidentally would be of great use in improving farm machinery selection procedures. Secondly, reliability surveys such as the ones by Anon[2] 1979, or Richardson, *et al* 1967, which list numbers and types of failures of various sorts of machines after the warranty period help manufacturers to identify and improve unreliable components and/or assemblies. Thirdly, more detailed surveys of times between successive failures (which may, of course be combined with the second type of survey, above), can be used to provide data on the operational reliability of single components, assemblies or whole machines as described below.

Analysis of reliability survey data

This aspect of reliability is mentioned because a knowledge of analytical procedures is useful in survey planning as well as processing the survey data.

Detailed surveys of times between failures mentioned in Section 6 yield data from which "observed" failure rates can be calculated and statistical inferences made about the failures rate of the populations of which the observed samples form a part.

Assuming a constant failure rate (that is, an exponential distribution of failure times, as in equation [1]), the observed failure rate is simply calculated as described in Section 2.

To test whether the failure times are exponentially distributed, the Kolmogorov-Smirnov goodness-of-fit test or the Chi-Square test may be used. However, since the data may not be exponentially distributed the versatile, three parameter Weibull distribution (Weibull, 1951) if often applied because by varying the parameter values, increasing, constant and decreasing failure rate patterns can be described. Application of the Weibull method to farm machinery failures is very clearly described by Kumar, *et al* (1977). For small samples and greater accuracy median ranking may be combined with the Weibull method (Johnson, 1951; Leaver and Thomas, 1974). This can be done quite easily by using Weibull probability paper to determine the distribution parameters and assign confidence limits.

Having obtained the Weibull parameters, the question then arises how to use them to predict probable times between failures for intended future machine use. The Monte-Carlo method is generally employed. In essence, this selects the value of a desired variable by repeatedly choosing a random number from its distribution so that the relative frequency of occurrence of an event (failure) can be obtained by carrying out a sufficiently large number of simulations, usually on a computer, (for example see Shooman, 1968). The computer program would be written so that the print-out gives the predicted time from start of operations to first failure, second failure, etc., and the mean time between failures for the total time (or other variable) being considered.

Conclusions

It seems likely that in the future more emphasis will be placed on farm machinery reliability, if only because of the introduction of legislation which, effectively, gives the farmer more power to claim compensation from the manufacturer or his agents when failures occur. However, the achievement of higher reliability is not only a problem for the manufacturers. If greater reliability is to be achieved without a very substantial increase in machinery prices, all related sections of the farming industry must assist the manufacturers; mainly by providing feed-back information as described in this paper.

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Baled silage and loader wagon silage

R R Morrison

HAY conservation is a major headache in our climate and whilst hay driers and mower conditioners help considerably, few would argue that silage is not a preferable product to hay. Not only has silage a greater production potential but its quality is more predictable than that of hay. At what cost and with which technique does one change from hay to silage when capital, labour and power are limited?

Making silage with the forage loader wagon and big round baler are two techniques which have appealed to the hay producer. They are said to meet the criteria of low labour, power and cost to some extent but neither meet all three criteria at the same time. The paper looks at these techniques and attempts to put them in perspective bearing in mind that the processes are not an end in themselves, only a means to an end. The type of silage required, that is, chop length, dry matter and fermentation quality, and the means of utilisation must also be considered in the production and planning stages.

Baled silage production

BALED silage made in big roll bales was first seen in Holland several years ago when high dry matter silage was made. I am often reminded that baled silage was made in Britain in the early 1950's with the conventional baler. Those who remember have the technique well engraved in their memories as one for the strong in back as well as in mind. With the introduction of the big baler full mechanical handling is possible, so many of the disadvantages of the early technique have been overcome. Big bale silage can now be made with several models of roll balers including those from New Holland, Farmhand, Gehl, Massey Ferguson and Claas. The Vicon rectangular baler has also been designed for this purpose and this adds a new dimension to baled silage.

Grass for baling is cut and wilted to 25-30% dm as for conventional silage. Grass maturity has a considerable bearing on the end quality so date of cutting must be considered. Younger grass consolidates well in the baler but if it is also short, problems may be experienced in the pick-up. Rotary mowers leave the stems complete with little bruising or laceration, mower conditioners improve wilting rate as well as disturbing the cuticular layer which makes the grass sugars more available for fermentation. Swaths may be put together before baling to aid wilting and to prepare the type of swath required by the baler. The swath shape has a considerable bearing on bale density, uniformity and subsequent stack stability.

High density bales are required to exclude air so that anaerobic conditions are developed as quickly as possible. A low forward speed, giving a large number of turns per bale, is desirable particularly in a dense swath. Bale size can be limited with most makes so that manageable units of 0.5 tonne are prepared. Twine is necessary and thin polypropylene twine is most suitable. Prepared bales are transported and ensiled as quickly as possible, a delay results in heating and subsequent poor fermentation. The baling process can proceed independently of transport and ensiling and thus is ideally suited to contracting or working with a limited labour supply.

Bale transport can be achieved with basic farm equipment such as buckrakes, bale transporters, flat trailers and a tractor front loader. Bales may be taken to the stack and stock-piled for later ensiling. Again this is an independent process with no tie to the baling or ensiling processes, unlike a chopping system where a team of three or four men are employed as a unit.

Although the Dutch have had some success with making baled haylage under a sealed double sheet, conditions in Britain are too rigorous and effective seals are rarely made and retained here. Even with effective sealing the nature of the silage is such that on opening deterioration is rapid with in one case a 9% dry matter loss being recorded over a 3-week period. Stacking round bales in clamps cannot be recommended at this stage.

The bagging process, developed three years' ago reduces the risk of major silage losses by restricting the effect of loss of seal to individual bales. Bags are made of 500 gauge black polythene to suit several bale sizes, and are long enough to permit a double tie at the neck. Black agricultural polythene tends not to be purchased on quality and although some higher grade polymers are produced which have greater strength and flexibility, these are generally not available for agricultural purposes.

The stack should be built on a firm dry base for easy winter access and be sheltered from the wind. To ensile, bales

are impaled, lifted and bagged taking care not to puncture the bag. The bale is then placed on the stack and once a face has been built, bags can be sealed using thick polypropylene twine. An industrial banding unit can be used for sealing but this is no quicker than hand tying. Stacks are best built outside covered with netting, the wet conditions reducing the risk of vermin infestations. The feeding process is simple, bales are debagged and placed in a bunker for self feeding or may be unrolled in a feed passage — often with difficulty. About 70% of bags can generally be used for a second year but careful checking of each bag is necessary.

Loader wagon silage

Silage making with a loader wagon, like baled silage, does not involve a team of men. The wagon itself is a means of chopping and transporting grass to the clamp.

Grass is cut and wilted again to 25-35% dm. Cutting with a mower conditioner or flail mower benefits the system by increasing the wilting rate and mixing the crop so that stems lie across the swath. Grass is lifted by a force feed mechanism through fixed knives into the transport box. The length to which grass is cut is influenced both by the presentation of the grass and the knife spacing. Close knife spacing may give a theoretical chop length of 50 mm but in practice chop length varies from 50 mm to full length depending on stem presentation.

Unlike precision and double chop harvesters the power required in cutting is low (10 kW through 70 mm knives) to some extent reflecting both the longer average chop length as well as the shearing process. Before defining this as a low power system one must also consider the draught power requirement which may be in excess of 30 kW when working in hill areas. The tractor size selected for operating the loader wagon must therefore reflect the topography to be encountered — this is why loader wagons are often seen behind high powered four-wheel drive tractors.

At the clamp grass can be discharged by using the floor conveyor to leave a heap of grass for buckraking into the silo. Rear discharge beaters are also available so that the wagon is able to discharge whilst driving over a 'bun' type of silo. Grass is often difficult to ensile because of the proportion of long material and so careful spreading is needed to ensure good even consolidation and the exclusion of air. This is a major problem with more mature, high dry matter forage which is difficult to compress, younger

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R R Morrison BSc MIAgrE is Senior Mechanisation Adviser, East of Scotland College of Agriculture

leafier grass is easier to ensile. As always good clamp sealing is an essential part of the conservation process. When unloading the silo, block cutters rather than dung forks are needed to restrict air entry into the silo. This air ingress accelerates the post opening deterioration to a greater extent than with precision chop silage because of the level of fermentation.

Silage quality

Both silage making processes involve ensiling fairly long material which has been gently harvested. This reduces field losses but to date no assessment of this has been made. The lack of bruising, laceration and chopping restricts the availability of grass sugars for fermentation and hence restricts lactic acid production. In baled silage grass is compressed into the bale and well sealed. Fermentation is restricted because of the lack of juices and in many silages high pH measurements have been found with very small fermentation losses. Failure in the seal renders the silage liable to post opening deterioration particularly if bales are of low density. This is why clamps of bales deteriorate badly when a seal is broken.

Silage prepared by loader waggons have often been characterised by poor fermentation. This is again due to restricted fermentation but is often accompanied by poor silo consolidation and ineffective sealing. The wilting is also important in concentrating sugars for fermentation but like baled silage, the high dry matter material has a higher pH and as such is more susceptible to air entry.

In considering silage quality, losses and livestock performances must also be reviewed. The in-silo loss level is very variable but recent monitoring at the East of Scotland College of Agriculture suggests fermentation losses of 5-10% for bales in bags compared with 10-20% fermentation losses accepted as the loss level for chopped silages. On the other hand baled silage has produced lower intakes and a 6% lower liveweight gain from beef finishing cattle when compared with precision chopped silage. This is to be expected with the longer material and a similar reduction is likely with the forage loader waggon silage.

Work rate

Making baled silage does not necessarily involve a team of men in a system. Baling can proceed independently of the transport system and a baling rate of approximately 10 t/h (18-20 bales/h) can be expected. Ensiling using a tractor loader, driver and two persons bagging can work at 22 bales/h (11 t/h). The transport rate reflects distance and technique, taking for example a trailer carrying 5 bales over 800 metres, the work rate is 7 t/h. An overall rate of 7 t/h may be expected for a four person system with the transport given. A maximum work rate of 10 t/h can be expected. This is thus

not a high work rate nor low labour system.

Loader wagons are able to harvest at a rate of 1 ha/h but as the harvester is also the transport system, the overall rate is directly related to the transport distance. Over an 800 metre distance an overall rate of 8 t/h with a 3 t load may be expected. With one man at the clamp ensiling and one harvesting, this is a low labour system.

System costs

Both techniques are readily adopted by a farmer moving from hay to silage and a number of capital items will already be available on the farm for forage conservation. Table 1 indicates the capital expenditure likely to be encountered in moving into either system. The investment and equipment is very similar but with a basic earthwall clamp, the storage costs for loader wagon silage swings the balance firmly in favour of baled silage.

In table 2 the annual mechanisation cost of production for a 10 hectare unit has been estimated assuming that only the capital items identified have been purchased for silage. The making costs relate to the depreciation, interests and repairs associated with those capital items. For hay production capital items costed include the conventional baler tedder and handling and transport systems. It can be seen that the loader waggon system costs more than both the baling system or hay making. The lower output per man hour of the baling system is seen in both the labour and tractor charge set against the system, this to some extent balances the baling system with the loader waggon system.

The production of forage from this 10 hectare area varies with technique as both field and storage losses are different. Table 3 compares the yield of grass from hay baled and loader wagon silage and applies conservation losses to these yields. The costs per ton of dry matter of baled silage and hay are similar with loader wagon silage costing approximately 15% more. The argument can be continued through livestock production, producing figures in terms of pounds sterling output per hectare as can be seen in table 4. This gives a clear advantage to baled silage over both loader wagon silage and hay.

However the costing is carried out for different mechanisation systems, it is unrealistic to stop short of the means of obtaining a return from the land, in this case the animal; it can be seen that the difference in the production cost of hay and silage is marginal, when compared with the total cost of concentrates usage to obtain production from livestock with these two different feeds.

The place of the system

Both techniques are suitable for farmers wishing to move out of hay making into a low cost silage system. Contracting the baling or harvesting can further reduce the capital costs from those shown but the change from contracting to ownership must depend on an individual farmer's business.

The loader wagon system is most suitable for a low labour situation. The observance of good silage making practices with the use of additives, can produce a satisfactory product. The power required for operating loader waggons on hills should not be underestimated. Long transport distances greatly reduce the potential work rate and may subsequently reduce silage quality. As a rule of thumb, the maximum quantity of silage that can be made per season with this system may be in the order of 800 tonnes with a single waggon. The capital charge for both the waggon and the silage clamp weigh heavily against the system when one considers that the farmers currently making hay are those who can least afford to change to silage.

Baled silage has a practical limit determined by the enthusiasm of the 'baggers'. Five hundred tons would seem sufficient where bags are being used. Existing farm equipment is suitable and so by contracting the baling, no long term commitment to the process is made. As grass is ready to be cut, it can be ensiled without disturbing earlier made material. Likewise the rate of usage can be varied without high losses occurring. The problem of protecting bags from vermin, wind, rogue cattle and small boys with pen knives should not be underestimated. One mousehole in a bag can make the difference between an excellent silage and something only suitable for the dung heap. With attention to detail the process can fit a high proportion of the smaller forage producers. As a salvage process, baled silage has proved invaluable over the last two years when conservation has often been very difficult. Those who use the technique should do so with some conviction, the quality should be determined by the stage of cutting not by the stage of rotting.

Table 1 System capital costs — Changing from hay

Baled		*Loader Wagon*	
Baler	£6000	Loader wagon	£7000
Loader adaption	£250	Buckrake	£500
Base	£1.40/t	Clamp (lined)	£12/t
Bags	£3.40/t	Sheeting	£200
(500 t silage)			
Capital cost (before grant)	£8650		£13,700

Table 2 Annual costs (10 ha)

	Making cost	*Labour at £1.9/h*	*Tractor at £3.3/h*	*Production cost*
Hay	1930	260	310	2500
Baled	2330	370	470	3170
Loader Wagon	2750	220	380	3350

1 cut hay – 7.5 t/ha
2 cuts silage – 30 t/ha

Table 3 Forage production (10 ha)

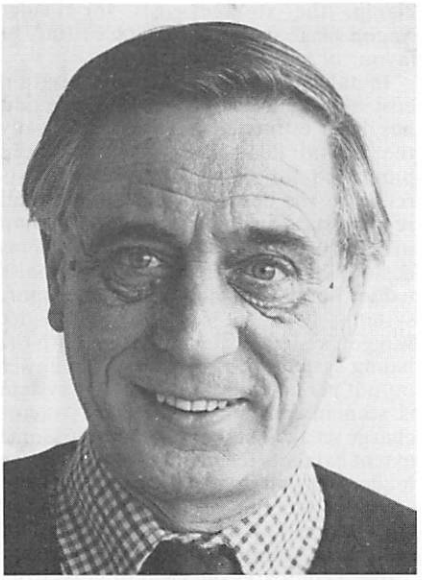
	Grass yield (tdm)	*Conservation losses (%)*	*Available forage (tdm)*	*Cost (£/tdm)*
Hay	68	20	54	463
Baled Silage	72	10	65	487
Loader Wagon Silage	72	20	58	577

Table 4 Returns for the three systems in terms of total costs/beef production

	Hay	*Baled silage*	*Loader wagon silage*
Tonnes dry matter fed	54	65	58
Consumption by 350 kg steers to achieve 0.9 kg/day gain (kgDM)	4.1	5.8	5.8
Beef production (tonnes)	11.8	10.1	9.0
Value of above at 80p/kg (A)	£9480	£8072	£7200
Concentrate usage (kg/day/head)	3.7	1.6	1.6
Concentrate costs (£/tonne)	95	90	90
Total usage of concentrate (tonnes)	48.7	17.9	16.0
Total cost of concentrate (B)	£4630	£1610	£1440
Forage production cost (C)	£2500	£3170	£3350
Net return: A = (B+C)	£2350	£3292	£2410

The mechanisation of mulch cultivation techniques

G E Lawson



Summary

I THINK that it is clear that, from a variety of sources, the basic principles of mechanising mulch and low tunnels techniques are established and could be applied in the UK. The one exception to this could be hoop and tunnel recovery, which could need a high clearance tractor, though one such machine does exist in Israel.

It is also clear that the technique could have some geographical and physical limitations and is undoubtedly best suited to the lighter soils in the South of England where the light levels are higher and the climate generally warmer.

Of course the mulch/low tunnel combination has been in use for a number of years in the UK for strawberries. But if it could be extended to other crops, and especially to those considered marginal in the field so far and those which may no longer be viable in the future in a heated situation, it could bring benefits to both grower and consumer. This form of culture may not be an economic proposition now, but I feel that it is essential to look some years ahead when circumstances could alter dramatically. Given that the mechanisation techniques exist I would like to see field trials established to really test the potential of the system.

Introduction

THOUGH the timing is indeterminate it is clear that liquid fossil fuels will eventually run out, or their costs may be too prohibitive for use with protected crops in horticulture. Similarly necessary mobile units such as tractors might be given priority over glasshouse heating as fuel becomes shorter in supply.

Coupled with this are the very high costs of erecting protected structures. Currently these are in the order of £250,000/ha for heated glass and £27,000 for a similar area of 'walk-in' polytunnels.

One answer to this problem could be an extension in the use of plastic mulches combined with low tunnels which could effectively extend the growing season of traditional crops, as well as improving quality and output, though not to the same degree as a heated and protected situation. The technique could also provide the opportunity to grow alternative or 'marginal' crops in the field, and this would help in our present state of over production as well as reducing some imports.

In comparison with conventional protected structures the mulch/tunnel combination costs around £2500/ha in the first year, and subsequently some £1500/ha/annum for replacement tunnel covers etc. The system has the additional benefit that it can be moved round a farm to fit in with a rotational cropping plan.

It is true that oil based plastics are used but mechanisation techniques should allow for the recovery of the film either for re-use or re-manufacture, and it is possible that cellulose material might be substituted and this stems from a renewable source.

G E Lawson TEng(CEI) MIAgrE, Agricultural Engineering Consultant

For such a system to be accepted into a developed horticultural situation it is essential that all field operations should be mechanised as far as possible.

The Japanese grow some 80,000 ha of crops under or through plastics, and this began in the Chiba area some 20 years ago and has extended rapidly ever since.

Japan was therefore an obvious choice for a study tour, and I was able to visit there in April 1980 under the sponsorship of the Douglas Bomford Trust and to whom I am deeply grateful.

Japanese horticulture

A brief explanation of Japanese horticulture is necessary to understand the forms of mechanisation for mulch and tunnel techniques that exist there. Light sandy or volcanic ash soils predominate and are very easily worked, and the climate is generally warmer than the UK with clear skies in the late winter and early spring.

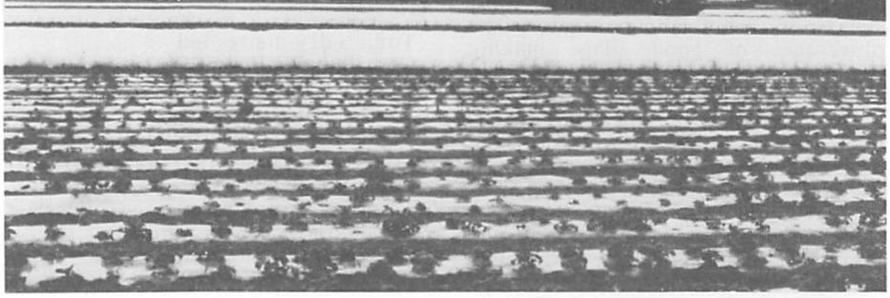
There are some 4,800,000 farms whose average size is only 1.2 ha, and a similar number of people are employed on the land. Whilst this means that a lot of hand labour is used it has not stemmed the move to mechanisation, and there are now 3 million two wheeled pedestrian operated tractors and more than 1 million four wheeled though of the latter 70% are less than 15kW. Even so it is probable that many of the techniques with plastics in the field could be scaled up to suit larger fields and prime movers.

Plastics mulch materials

Whilst many of the materials for mulches and tunnel covers are the same as those used in Europe, there are some in Japan which are novel. The most significant of these is a clear polythene film which is impregnated with either Diphenamid or Prometryne herbicides during manufacture. These chemicals will exude for up to three weeks once the film is layed on the soil and effectively kill any emerging weed seedlings, though obviously perennials have to be dealt with beforehand.

This clear polythene allows higher soil temperatures to be achieved at night and overcomes the problem with black materials which though it inhibits weed

The Chiba area in Japan is virtually a "sea" of plastics which form the mulches, low tunnels, and walk-in tunnels



growth completely does result in lower temperatures.

Another film (black or clear) has a series of white stripes running longitudinally, and this is claimed to deter aphids who do not like the light they reflect and fly away.

Similarly, they have many more pre-perforated films giving a vast range of different plants spacings and patterns, which when layed can be seeded or planted through the holes. This type could also be used at a harvesting to lift a crop, and certainly for lettuce, and this has been done by the CNEEMA in France.

Mulch laying machinery

Bearing in mind the light soils in Japan much of their equipment appears lighter in construction than those of European origin.

The most significant difference is that the layer is invariably used in conjunction with a rotary cultivator, whether operated by a two or a four wheeled tractor.

For laying the plastics on a flat or slightly 'crowned' bed the rotary cultivator is fitted with its normal tines with the mulch layer close coupled. However, between the two is fitted a 'moulding' blade which produces the bed shape, and usually the two small furrows at each side in which the edges of the plastic will be buried.

The film is payed out from a roll as the machine progresses and stretched over the soil by tyred wheels, and the edges secured by soil placed over them by angled discs.

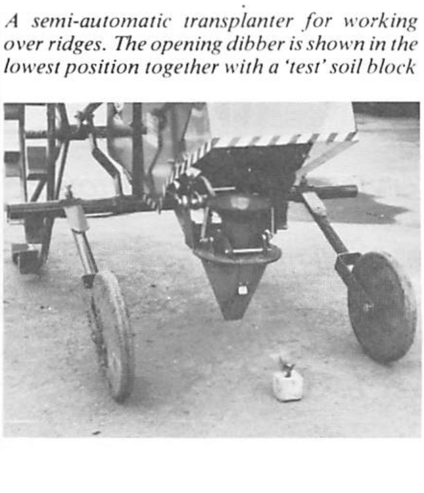
The result is very good indeed with the film in intimate contact with the soil to derive the maximum soil warming effect.

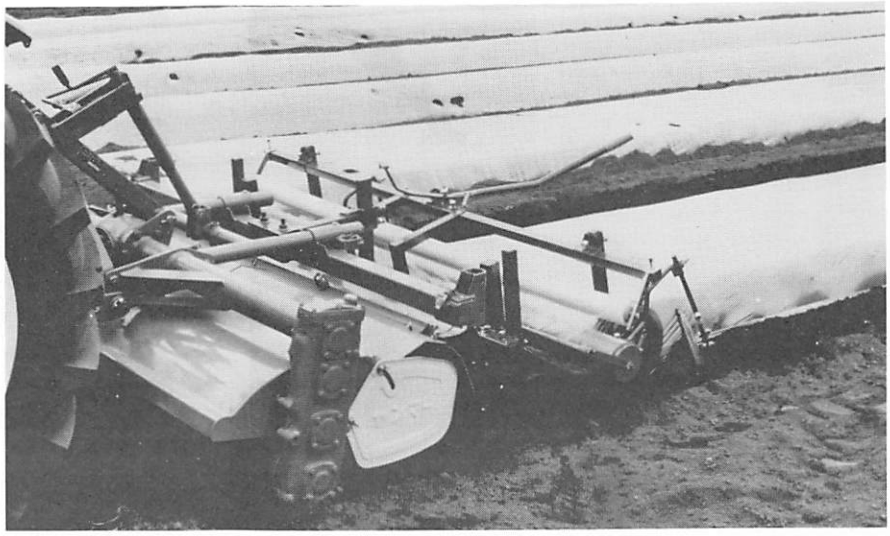
Many Japanese crops, for example tomatoes, melons, tobacco, and sweet potatoes, are grown on truly semi-circular ridges and these too may be covered with a plastic mulch.

The basic configuration of the machinery remains the same except that the tines of the rotary cultivator are replaced with opposite handed helicoidal blades at each side. These have the effect of throwing the soil towards the centre where it is shaped into a rounded ridge and the plastic layed over.

In general these machines tend to be single row fitted to a pedestrian operated tractor, but larger two row models exist for use with larger prime movers.

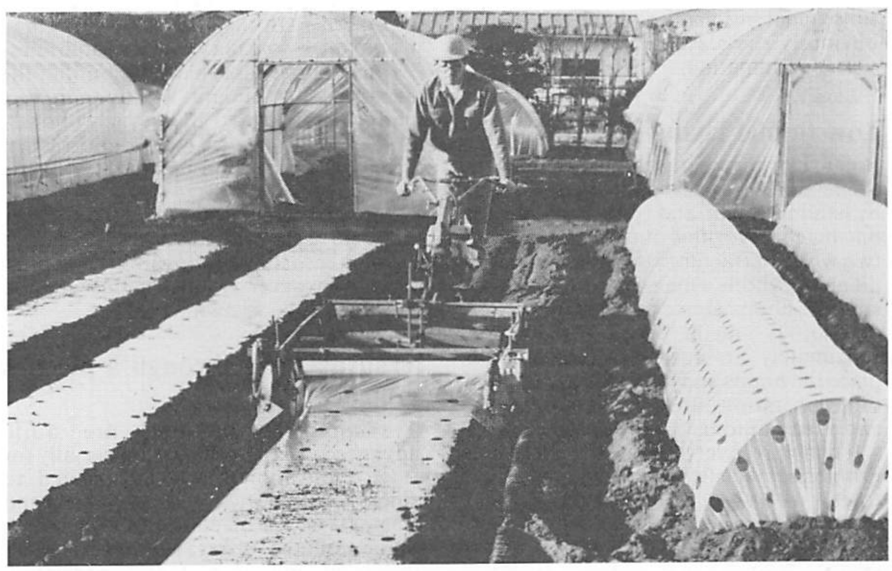
A semi-automatic transplanter for working over ridges. The opening dibber is shown in the lowest position together with a 'test' soil block



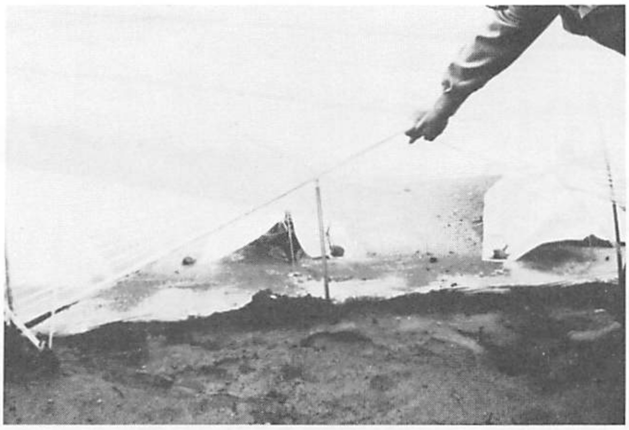


This typical arrangement shows the rotary cultivator with a tandem mounted mulch layer forming and covering a slightly raised flat bed

A pedestrian operated two wheeled tractor fitted with a rotary cultivator and mulch layer, and shown here laying a pre-perforated mulch for subsequent hand planting or seeding. The operator in this case has to walk backwards



A combined ridge former and mulch layer fitted to a two wheeled tractor. Note the helical blades which throw the soil towards the centre to form the ridge



The crop being established here is planted through a plastics mulch and under a low tunnel. As an additional aid little plastics 'hats' are placed temporarily over each plant and will be removed later.

In this Japanese house the lettuce crop is growing through a mulch. At an earlier stage it was covered under the low tunnels, whilst it is also fitted with a plastics thermal screen inside and yet another outside which can be placed over in very cold weather. In all an incredible series of five layers of plastics between soil and sky

In either case the result is very regular and should materially assist any subsequent mechanical harvesting, and obviously the plastics film limits undue soil contamination.

Low tunnel laying

Because of the relatively small field sizes tunnel films or covers are usually laid out by hand in Japan, and I only encountered one machine for this purpose. This was a two wheeled tractor fitted with very large diameter wheels which would enable it to straddle hoops already placed in the soil, and so pay out the plastics from a reel. Fortunately an automatic machine to place the hoops and lay out a cover in the same operation already exists in Israel, and a semi-automatic machine in France.

Tunnel recovery may still present a problem especially as it would require a tractor with a ground clearance of around 600 mm, and these are rare.

Seed sowing through a plastics mulch

Field sizes and the abundance of hand labour means that most sowing through mulches, usually pre-perforated, is done with simple hand operated seeders.

Though the Japanese are working on combined precision drill and perforators I doubt whether they are any more advanced than the French and German Companies working along the same lines.

One relatively simple solution that the Japanese MAFF are working on is a perforator followed by a synchronously driven precision drill with the object of dropping the seed through the holes made in the plastics.

In fact the seed is dropped 'late' rather than 'early', and should it miss the hole it is swept into it by a following 'vee' shaped brush. However results of this method have yet to be known.

Transplanting through a plastics mulch

Transplanting methods are quite advanced in Japan and used especially for ridge cultivation but again limited to single row operation by virtue of field and tractor size. The machines are either three point mounted on a tractor or form a self propelled unit as part of a pedestrian operated machine, and most employ an opening dibber working with a 'paddle' motion so that the dibber approaches the ground or mulch at ground speed. Here, by virtue of its shape, it pierces the mulch and releases the paper pot or soil block transplant into the soil.

These machines are semi-automatic in operation since the dibber is charged with transplants at the top of its stroke by a rotating feed mechanism kept supplied by an attendant operator.

This operator is also the driver in some cases with the pedestrian type machines.

An additional refinement is possible with transplants on a ridge. Whilst these can be transplanted through a mulch layed simultaneously on a pre-formed ridge, it is also possible to plant them deep into the ridge and cover them immediately afterwards (in the same operation) without piercing. In this way they are protected in a favourable environment whilst they establish, and the plastics is subsequently pierced by hand at a suitable stage to allow the plants to grow through. Though the single row units predominate in Japan at the moment tractor sizes are increasing and its seems likely that two row units will evolve, and there appears to be no undue problems in making multiple units.

Acknowledgements

The Douglas Bomford Trust.
The Science and Technology Dept, British Embassy, Tokyo.
The Japanese MAFF, and many other research establishments and Commercial companies in that country that I visited.

Mechanisation of potatoes/root crops

MECHANISATION of potatoes/root crops was the subject of the latest members' day of the British Society for Research in Agricultural Engineering. The Association, formed to bring farming, manufacturing and research together, held two separate days for members on the subject at each of its bases, Scottish Institute of Agricultural Engineer, Penicuik, Midlothien (SIAE) on 30 September and National Institute of Agricultural Engineering, Silsoe, Bedford (NIAE) on 8 October. As is the norm for these days there was plenty to see and a choice of simple detailed information on exhibits to satisfy both the passing observer and those with a keen interest. Potatoes and sugar beet were the main crops covered with the SIAE demonstrating a wide range of potato machinery at both events.

Potatoes

Cultivation and planting

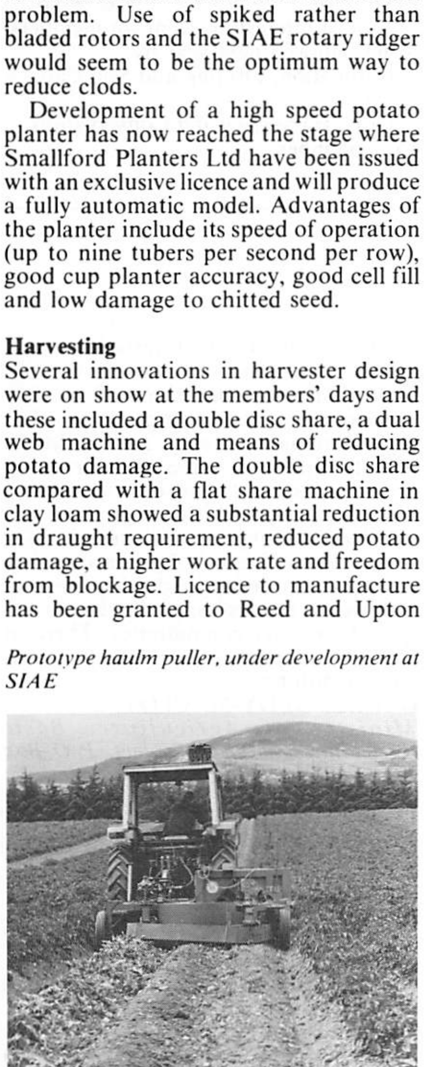
The clod problem is still under scrutiny at SIAE and although soil type is the major factor influencing clod population, cultivating, ridging or spraying at high soil moisture contents can exacerbate the problem. Use of spiked rather than bladed rotors and the SIAE rotary ridger would seem to be the optimum way to reduce clods.

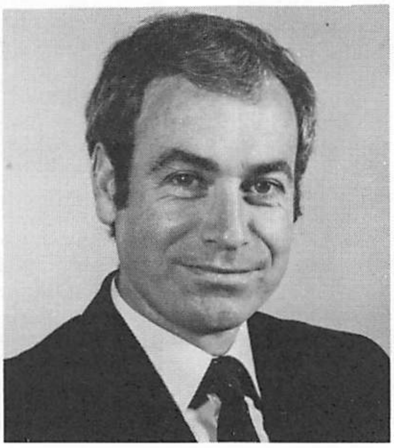
Development of a high speed potato planter has now reached the stage where Smallford Planters Ltd have been issued with an exclusive licence and will produce a fully automatic model. Advantages of the planter include its speed of operation (up to nine tubers per second per row), good cup planter accuracy, good cell fill and low damage to chitted seed.

Harvesting

Several innovations in harvester design were on show at the members' days and these included a double disc share, a dual web machine and means of reducing potato damage. The double disc share compared with a flat share machine in clay loam showed a substantial reduction in draught requirement, reduced potato damage, a higher work rate and freedom from blockage. Licence to manufacture has been granted to Reed and Upton

Prototype haulm puller, under development at SIAE





W C T Chamen

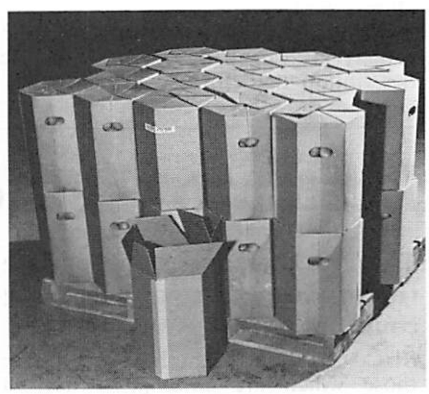
Ltd, who are fitting it to two row unmanned harvesters. The dual web harvester worked on the principle of hand removing large clods from amongst large potatoes on a gently agitated widely spaced web, and removing small potatoes conveyed from an inner narrow spaced web again with little or no agitation. Performance on the day was limited because of incompatability of row spacing, but figures suggest an increased work-rate compared with similar types of harvester and 27% reduction in damage index.

Of particular interest to me was the work done by Malcolm McGehan of SIAE who has been investigating the effect of riddling motions on potato damage and separating efficiency. Experiements on two soil types and six maincrop varieties showed that a horizontal motion of the riddle bars rather than the vertical one presently used on most machines, removed soil more efficiently and reduced potato damage. There was little to choose between horizontal movement along or across the riddle bars, but it was concluded that there was an urgent need to redesign potato harvesters to include a horizontal rather than a vertical shaking motion. This could reduce potato damage more significantly than either growing damage resistant varieties or adjusting existing vertical riddling systems.

Handling

For bulk conveyors developments to reduce potato damage consisted of an automatic height control unit and a double telescopic attachment. The former consisted of a sensor ball and air-switch connected via a control box and solenoid valve to a hydraulic ram. The system worked on the principle of constantly moving the conveyor to "touch" the bed of the lorry or pile of potatoes with its sensor ball. The ball upon touching would then signal the conveyor to retract which it would do for a fixed short period only to repeat the procedure again. Frequency of this cycle and rate of retraction were adjustable and could be matched to a wide range of tractor hydraulics. The double telescopic attachment could also be fitted with this sensor ball but its main feature was a deep flighted elevator which was attached to the end of the main elevator, from which it took its drive. Attachment was such that this deep flighted conveyor could be retracted beneath the main elevator and also be pivoted around it.

Still on the subject of handling, SIAE showed an ingenious device for grading vegetables and fruit. This had the advantage of being a steplessly variable grader capable of producing three grades . The machine used parallel steel rollers mounted on short upstands from two heavy roller chains. These continuous chains, about a metre apart ran over two pairs of leaf spring guide tracks, one pair having the rollers above them and the other pair with the rollers below. Potatoes, for example, would be elevated to the rollers as they passed over the top leaf springs. The largest fraction could remain on the outside of the rollers, while small and medium potatoes would pass via short elevators to the rollers as they passed over the bottom leaves. Here medium sized potatoes would remain inside the rollers and small ones drop through. Conveyors at appropriate points picked up the various grades while handles adjusted the arch of the leaf springs and thus grade sizes.

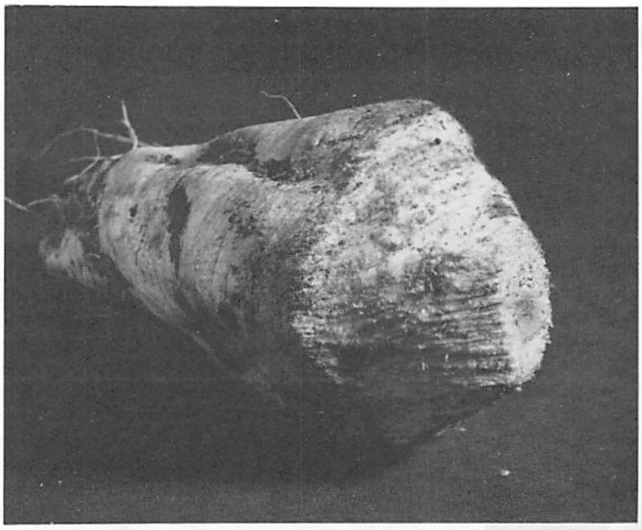


Development in packaging to reduce potato damage, 25 kg size hexagonal cartons

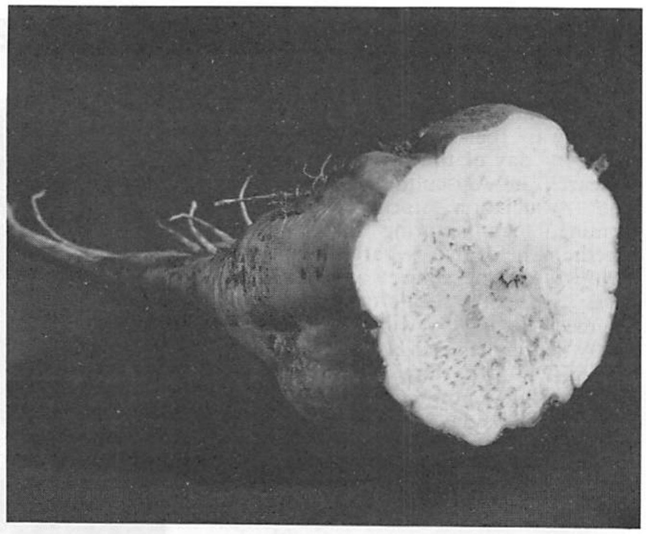
Sugar beet

Drilling of sugar beet has always been a slow process and it is gratifying to note that the NIAE developed two stage drill, capable of sowing seed accurately at nearly 7 mile/h, is now selling well as the Thomas drill. NIAE research is now concentrating on seed germination and emergence with an experimental unit capable of placing seeds at a predetermined position in the soil profile and manipulating the soil environment. Once the plant is established, other work at NIAE has suggested that growing beet in beds can be advantageous in terms of sugar yield by virtue of better interception of solar radiation.

Sugar beet harvester design has also made significant progress over the past few years, first with the new cleaner mechanism designed specifically for difficult soil conditions and latterly with the brush topper. The new concept in beet



Brush topped root



Beet correctly topped to BSC standard

cleaning consists of a pair of contra-rotating cylindrical cages separated by a smooth faced oscillating roller of small diameter. Thorough but gentle cleaning is provided by having the bars in the cylinders free to move tangentially in their supporting discs, as the beet pass down the upper surfaces of the variable slope of the cylinders and roller. This system is probably unique in being able to remove large quantities of soil, trash and all but the largest stones.

"A new and valuable way of more effectively topping beet" is the description used for the brush topper. This consists of a cylindrical wire brush, wide enough to encompass the whole top of a beet, and at present, rotating in the same plane and sense as the harvester ground wheels. Conventional and brush topping are shown in the figures opposite, the advantage of the latter being complete removal of leaf petiole, a 10-15% increase in root weight and 12-15% increase in sugar content. Although invert sugar content was increased by 14-18%, the percentage would probably be much lower if compared with a commercial load of beet. Assuming the present problem of brush life versus cost is resolved, this looks a particularly promising new development.

Many other facets of these two crops were shown and it was good to see exhibits from the Potato Marketing Board and the East & North of Scotland Colleges of Agriculture highlighting developments in storage and grading.

A most interesting event for members, to be followed next year by:

Cultivation, Drilling and Soil Care — 26 May

Grass Harvesting and Conservation — 15 September

WCTC

Letter to the Editor

The introduction of appropriate technology in developing countries

SUCCESSFUL examples of AT are those which are developed within a community in response to a given need. The technology must be designed to utilise the resource base which exists locally and be a product of individuals who act within the given socio-cultural and economic structure.

Technologies introduced from external sources where people from outside a community are responsible for defining needs and proposing solutions often prove ineffective for the community. Sophisticated technologies designed under completely different circumstances have often been wrongly transplanted, usually unmodified, into a community in a developing country.

The major concern for the people is that they can support, rather than resist, the introduction and use of the technique. Success is judged by the extent to which the community adapts to the new technology. Most people tend to resist change if their basic securities are threatened or if they do not understand what is actually happening or if changes are being imposed on them.

The AT approach stresses an integrated community development which is dynamic, in that the community itself is involved in determing the nature, method and pace of introduction of a new technology. The community identifies its own needs and priorities and finds the necessary internal and external resources to meet these. Alternatively a new technology is adapted by the people until it is seen appropriate for them, then its use will become embedded in the every day life of the community.

The stress on need is the first step in the development process of AT. It is the members of a community who have a problem who should define that problem in terms which are relevant and familiar to the community. Difficulties arise where there is a lack of articulation of needs at the field level. People may be unaware that there is a wide range of technical choice and difficulties may arise if there has been a lack of articulation of needs, and problems and solutions are defined by foreigners in terms of Western concepts and industrial conditions.

If at the village level a project is successful people will be less apathetic about trying another. So it is important that local leaders and community members are involved from the concept of a new technology to its installation and use and acceptance.

With the introduction of a new technology it is important that organisational patterns and technical maintenance be created. Training procedures should equip individuals with new skills with which to improve the standard of living in their community.

If an AT is successfully introduced as part of an integrated development process it is always hoped that its use will spread to other communities. There, it can be readapted to suit different needs and conditions.

O A KENNEDY-MACFOY,
Ministry of Agriculture, Basic Agricultural Services Project, P O Box 24, Maseru, Lesotho, S Africa.

Book Reviews

Oilseed Rape Book

THE oil seed rape crop is now well established in the United Kingdom as an important arable crop following a dramatic increase in the area of production during the last decade. This occurred initially in response to a need for a suitable breakcrop in the arable areas of the country, but more recently strong intervention support has made the crop into a profitable cash crop in its own right.

Accompanying this rapid expansion there has, inevitably, been a need for information and knowledge on all aspects of production and marketing of rapeseed. This book brings together the knowledge and experience of many contributors who have been closely involved with the development of the crop during this period.

Preliminary chapters describe the origins of the crop and its introduction into UK agriculture including consideration of its soil and climatic requirements. Subsequent chapters deal with crop establishment, fertilizer requirements, crop protection, harvesting, drying, storage and marketing. A useful list of agricultural contractors with specific expertise in growing and harvesting the crop is also provided.

The book provides a sound technical base for those interest in familiarising themselves with the crop. As a manual providing specific recommendations on such aspects as choice of variety and crop protection it will inevitably become outdated very quickly. Nevertheless it will appeal to farmers, advisers, students and anyone interested in gaining a practical knowledge of the oil seed rape crop.

Oilseed Rape Book, a manual for growers farmers and advisers; Cambridge Agricultural Publishing.

EJE

Irrigated Rice Production Systems

IN the true spirit of agricultural engineering, *Irrigated Rice Production Systems* attempts to bring together the disciplines of engineering and agronomy to examine appropriate systems for irrigated rice production.

For some time now there has been an increasing demand for specialist texts of this type, particularly for the more important food crops. The authors concentrate on paddy (or wetland) rice drawing most of their information from experience in the Philippines. They give emphasis to the interaction between engineering design and the social and economic requirements of rice production.

The book is wide in scope and includes sections on hydrologic data analysis, irrigation system design, flood control, system design for rice production and project evaluation. The section on hydrology is rather large, covering almost one third of the book and obviously reflects the authors experience in assessing water resources in high rainfall areas for rice production. There is even a chapter on tropical cyclones.

Throughout the book extensive use is made of published research work. The authors take the opportunity to present some of their own work for the first time, particularly in the sections dealing with the irrigation system design. New ideas are put forward for the re-organisation of water distribution in rice schemes to reduce canal capacities which can be extremely high at times of land soaking. However, little evidence is presented on their successful use in practice and so the designer would need to view these techniques carefully in the light of his own experience.

The book will surely be of interest to students, practising engineers and agriculturalists working on irrigated rice. If not providing all the working details for the designer, it will certainly cause many to think more fully about this important crop.

Irrigated Rice Production Systems by Jaw-Kai Wang and Ross E Hagan; published by Westview Press, Boulder, Colorado, USA; price $35

MGK

The Economics of Irrigation

THE Economics of Irrigation represents an extensive revision and updating of Colin Clark's book of the same name, the second edition of which was issued by Pergamon Press in 1970 and which has been out of print since 1973.

As with earlier editions this book is addressed to all those who have responsibility, direct or indirect, for spending money on irrigation, whether for small schemes or large, whether private or public whether in arid or humid climates. It aims to give agriculturalists, engineers, planners and politicians a wider view of the implications of irrigation development than their own individual disciplines, experience and prejudices often allow.

Most of the chapters are expanded versions of those found in the second edition. These include Chapter 2 Water requirements of plants (which I found to be rather muddled and confusing with unnecessary attention given, in a book of this nature, to detailed aspects of crop physiology) Chapter 3 Water resources and their exploitation, Chapter 5 The cost of irrigation (which includes an interesting comparison of relative costs of so-called primitive and power pumping) Chapter 6 The economic returns to irrigation and Chapter 7 Charges for water. This last chapter includes a valuable review of the problems of how to determine a realistic basis for water charging and how then to select a reliable method of measurement. Two excellent new chapters include Chapter 4 Groundwater economics, and Chapter 8 Planning irrigation development in which there is an amusing section on the attitudes of the various interest groups involved in irrigation development. Cost comparisons between countries and across time are made by relating everything to the value of the US dollar in 1974 or sometimes in terms of wheat equivalents, a useful index.

This book highlights a dilemma facing anyone revising an earlier edition especially when a new author is involved. Large parts of the second edition are repeated word for word with the same tables and figures many of which have not been updated. Interspaced with this are the new sections, usually describing recent experience or research, which often contrast markedly in style and presentation. As a non-economist it was these sections which I found most rewarding and in many ways it is a pity that the book could not have been completely rewritten.

The book has an excellent bibliography and a comprehensive index. Notes and references on each chapter are given at the end of the book. Unfortunately there are the inevitable printing errors some of which are important.

This, therefore is a rigorous and detailed analysis of an extremely complicated subject and must be recommended to anyone involved in irrigation development. At the very least it will make more people aware of the wider implications of what they are doing, and of the need to consider alternative ways of allocating limited resources within and between projects.

The Economics of Irrigation, by Ian Carruthers and Colin Clark, Liverpool University Press, 1981.

MKVC